



# Basic Research Plan

February 2003



Published by  
Department of Defense  
Director, Defense Research & Engineering

Report Documentation Page				Form Approved OMB No. 0704-0188	
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.					
1. REPORT DATE <b>00 FEB 2003</b>		2. REPORT TYPE <b>N/A</b>		3. DATES COVERED <b>-</b>	
4. TITLE AND SUBTITLE <b>Basic Research Plan, February 2003</b>				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) <b>Department of Defense, Director, Defense REsearch and Engineering, 3040 Defense Pentagon, Washington, DC 20301-3040</b>				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT <b>Approved for public release, distribution unlimited</b>					
13. SUPPLEMENTARY NOTES <b>The original document contains color images.</b>					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT <b>UU</b>	18. NUMBER OF PAGES <b>139</b>	19a. NAME OF RESPONSIBLE PERSON
a. REPORT <b>unclassified</b>	b. ABSTRACT <b>unclassified</b>	c. THIS PAGE <b>unclassified</b>			



Department of Defense  
Director, Defense Research & Engineering  
3040 Defense Pentagon  
Washington, DC 20301-3040



The *Basic Research Plan* is a dynamic document that is updated every two years. It describes ongoing work as well as planning activities and past accomplishments that can be traced to earlier basic research. It serves to inform both performers and managers of the research as well as to provide military planners with an overview of the entire program. Its ultimate purpose is and remains that of providing the warfighter with superior and affordable technology, whether waging war or enforcing the peace.

This fifth edition of the *Basic Research Plan* is an updated and amplified version of the February 2001 Plan. Each plan serves to focus, integrate and describe the Department of Defense (DoD) investment in a world-class research program. To link basic research to broad, revolutionary 21<sup>st</sup> century military capabilities requires planning. In the case of a strategic program like basic research, planning involves not so much solving individual problems, but rather whole strategic technology areas that should address still unrealized but envisioned future military capabilities. Historically, basic research has initiated scientific and engineering breakthroughs that started previously undreamed of technological revolutions. There is no reason to doubt that we can do so again.

What is new in this fifth edition of the *Plan* is the emphasis we have placed on speeding the conversion and transfer of rapidly advancing basic research into technology areas with the potential for achieving high military payoff. To accomplish this objective requires earlier and informed planning based on broad strategic Defense requirements. Suitable ongoing research efforts are therefore directed (but without interfering with the basic research process itself) toward a common strategic goal that has the potential of attaining radically new military capabilities. This is the purpose of the *Strategic Research Areas*, which are described in detail in this *Basic Research Plan*. This year's *Plan* is again a joint product of the Office of Basic Sciences working with the Research Offices of the Military Departments and Defense Agencies.

A handwritten signature in black ink, likely belonging to Dr. John Hopps.

Dr. John Hopps  
Deputy Under Secretary of Defense  
(Laboratories & Basic Sciences)

A handwritten signature in black ink, likely belonging to Dr. William Berry.

Dr. William Berry  
Director for Basic Sciences

## CONTENTS

<b>I.</b>	<b>EXECUTIVE SUMMARY.....</b>	<b>I-1</b>
A.	DEFENSE BASIC RESEARCH VISION.....	I-2
B.	DEFENSE BASIC RESEARCH MISSION.....	I-2
C.	UNDERSTANDING WARFIGHTER NEEDS .....	I-3
1.	Information Assurance .....	I-3
2.	Battlespace Awareness .....	I-3
3.	Force Protection .....	I-4
4.	Reduced Cost of Ownership .....	I-4
5.	Maintaining a Balanced Basic Research Portfolio .....	I-4
D.	OBJECTIVES OF DEFENSE BASIC RESEARCH .....	I-4
E.	TRANSFORMATION INITIATIVES .....	I-6
F.	THE PAYOFF .....	I-7
1.	Global Positioning System.....	I-7
2.	Night Vision Technology .....	I-7
3.	Airborne Laser .....	I-8
4.	Internet and World Wide Web .....	I-8
5.	Satellite Technology .....	I-8
6.	Stealth Technology .....	I-8
<b>II.</b>	<b>THE PLANNING PROCESS.....</b>	<b>II-1</b>
A.	ROLE OF SERVICES AND AGENCIES IN BASIC RESEARCH PROGRAM.....	II-1
B.	BASIC RESEARCH AND THE RELIANCE PROCESS .....	II-1
C.	A FLEXIBLE AND BALANCED INVESTMENT PORTFOLIO.....	II-2
D.	QUALITY AND RELEVANCE OF BASIC RESEARCH PROGRAM.....	II-3
1.	Scientific Planning Groups .....	II-3
2.	Strategic Research Area Coordinating Groups .....	II-3
3.	Defense Basic Research Advisory Group .....	II-3
4.	Defense Basic Research Review Panel .....	II-3
5.	Non-DoD Government Scientific Planning Group Review Panel.....	II-3
6.	Deputy Under Secretary of Defense for Laboratories and Basic Sciences ....	II-3

<b>III.</b>	<b>DEFENSE BASIC RESEARCH PROGRAM OVERVIEW .....</b>	<b>III-1</b>
A.	CHARACTER AND MANAGEMENT OF PROGRAM.....	III-1
1.	Character of Defense Basic Research .....	III-1
2.	Management of Defense Basic Research .....	III-1
3.	Strategic Research Areas.....	III-1
4.	International Strategy .....	III-1
B.	COMPOSITION OF PROGRAM .....	III-2
1.	Defense Research Sciences .....	III-2
2.	University Research Initiative.....	III-2
3.	Other Programs .....	III-3
C.	SCIENCE EDUCATION AND INFRASTRUCTURE SUPPORT .....	III-14
D.	TRANSITIONS FROM BASIC RESEARCH TO APPLICATIONS .....	III-14
<b>IV</b>	<b>DEFENSE BASIC RESEARCH FUNDING .....</b>	<b>IV-1</b>
A.	FUNDING COMPARISONS .....	IV-1
1.	DoD and Other Federal Basic Research Funding .....	IV-1
2.	FY03 Appropriations for DoD Science and Technology.....	IV-1
3.	Funding for Performers of Defense Basic Research .....	IV-3
4.	Funding Comparisons by Disciplinary Areas .....	IV-3
B.	TOTAL FY99-04 FUNDING FOR DEFENSE BASIC RESEARCH .....	IV-4
<b>V.</b>	<b>BASIC RESEARCH AREAS.....</b>	<b>V-1</b>
A.	ATMOSPHERIC AND SPACE SCIENCES .....	V-1
1.	Meteorology .....	V-2
2.	Space Science.....	V-2
3.	Remote Sensing.....	V-3
B.	BIOLOGICAL SCIENCES .....	V-4
1.	Molecular/Cellular .....	V-5
2.	Systems/Organisms .....	V-5
3.	Biomedical .....	V-6
C.	CHEMISTRY .....	V-7
1.	Materials Chemistry .....	V-8
2.	Chemical Processes.....	V-8
D.	COGNITIVE AND NEURAL SCIENCE .....	V-9
1.	Human Performance.....	V-10
2.	Reverse Engineering .....	V-10

E.	ELECTRONICS .....	V-11
1.	Solid-State and Optical Electronics .....	V-12
2.	Information Electronics.....	V-12
3.	Electromagnetics .....	V-12
F.	MATERIALS SCIENCE.....	V-13
1.	Structural Materials.....	V-14
2.	Functional Materials.....	V-14
G.	MATHEMATICS AND COMPUTER SCIENCES.....	V-15
1.	Mathematics .....	V-16
2.	Computer Sciences.....	V-17
H.	MECHANICS.....	V-18
1.	Solid and Structural Mechanics .....	V-19
2.	Fluid Dynamics .....	V-19
3.	Propulsion and Energy Conversion.....	V-20
I.	PHYSICS.....	V-21
1.	Energy Production and Electromagnetic Radiation .....	V-22
2.	Matter and Materials .....	V-22
3.	Sensing Detection .....	V-23
J.	TERRESTRIAL AND OCEAN SCIENCES .....	V-24
1.	Terrestrial Sciences .....	V-24
2.	Ocean Sciences.....	V-25
K.	DISTRIBUTION OF FUNDING AMONG THE RESEARCH AREAS .....	V-28
<b>VI.</b>	<b>STRATEGIC RESEARCH AREAS.....</b>	<b>VI-1</b>
A.	BIOENGINEERING SCIENCES .....	VI-2
1.	Objective .....	VI-2
2.	Thrusts.....	VI-3
3.	DoD Applications .....	VI-3
B.	HUMAN PERFORMANCE SCIENCES.....	VI-5
1.	Objective .....	VI-5
2.	Thrusts.....	VI-5
3.	DoD Applications .....	VI-5
C.	INFORMATION DOMINANCE.....	VI-6
1.	Objective .....	VI-6
2.	Thrusts.....	VI-6
3.	DoD Applications .....	VI-6

D.	MULTIFUNCTION MATERIALS.....	VI-7
1.	Objective .....	VI-7
2.	Thrusts.....	VI-7
3.	DoD Applications .....	VI-7
E.	NANOSCIENCE .....	VI-8
1.	Objective .....	VI-8
2.	Thrusts.....	VI-8
3.	DoD Applications .....	VI-8
F.	PROPULSION AND ENERGETIC SCIENCES .....	VI-9
1.	Objective .....	VI-9
2.	Thrusts.....	VI-9
3.	DoD Applications .....	VI-9
G.	SUMMARY AND FUNDING .....	VI-11
<b>VII. MULTIDISCIPLINARY UNIVERSITY RESEARCH INITIATIVE.....</b>		<b>VII-1</b>
<b>VIII. BASIC RESEARCH SUCCESS STORIES .....</b>		<b>VIII-1</b>
 <b>APPENDIX A: PRINCIPAL POINTS OF CONTACT.....</b>		<b>A-1</b>
<b>APPENDIX B: REFERENCES.....</b>		<b>B-1</b>
<b>APPENDIX C: GLOSSARY OF ABBREVIATIONS AND ACRONYMS .....</b>		<b>C-1</b>

## FIGURES

III-1	Annual DEPSCoR Funding to States, FY91-03 .....	III-6
IV-1	Comparison of FY02 and FY79 Basic Research Funding Managed by Federal Agencies.....	IV-1
IV-2	FY03 DoD S&T Appropriations Budget .....	IV-2
IV-3	Distribution of DoD FY03 Basic Research Program Funding .....	IV-2
IV-4	Distribution of FY03 S&T Funds Among Basic Research, Applied Research, and Advanced Technology Development.....	IV-2
IV-5	Performers of Defense Basic Research in FY03.....	IV-3

**TABLES**

III-1	MRI Topics .....	III-12
III-2	FY02 MRI Selections .....	III-12
IV-1	DoD Percentage of Federal Funding to Universities—FY02 .....	IV-4
IV-2	DoD Basic Research Funding by Program Element for FY99-04 (\$Millions).....	IV-5
V-1	Service-Specific Interests and Commonality in Atmospheric and Space Sciences.....	V-4
V-2	Service-Specific Interests and Commonality in Biological Sciences .....	V-7
V-3	Service-Specific Interests and Commonality in Chemistry .....	V-9
V-4	Service-Specific Interests and Commonality in Cognitive and Neural Science.....	V-11
V-5	Service-Specific Interests and Commonality in Electronics.....	V-13
V-6	Service-Specific Interests and Commonality in Materials Science .....	V-15
V-7	Service-Specific Interests and Commonality in Mathematics and Computer Science .....	V-17
V-8	Service-Specific Interests and Commonality in Mechanics .....	V-21
V-9	Service-Specific Interests and Commonality in Physics .....	V-23
V-10	Service-Specific Interests in Terrestrial and Ocean Sciences.....	V-27
V-11	Basic Research Funding by Service for Each Research Area (\$Millions) .....	V-28
VI-1	Correlation of Strategic Research Areas and Scientific Disciplines.....	VI-2
VI-2	Funding Profiles for Basic Research Supporting Strategic Research Areas (\$Millions) .....	VI-12
VII-1	Potential Payoff of MURI Program Research .....	VII-3

# CHAPTER I

## EXECUTIVE SUMMARY

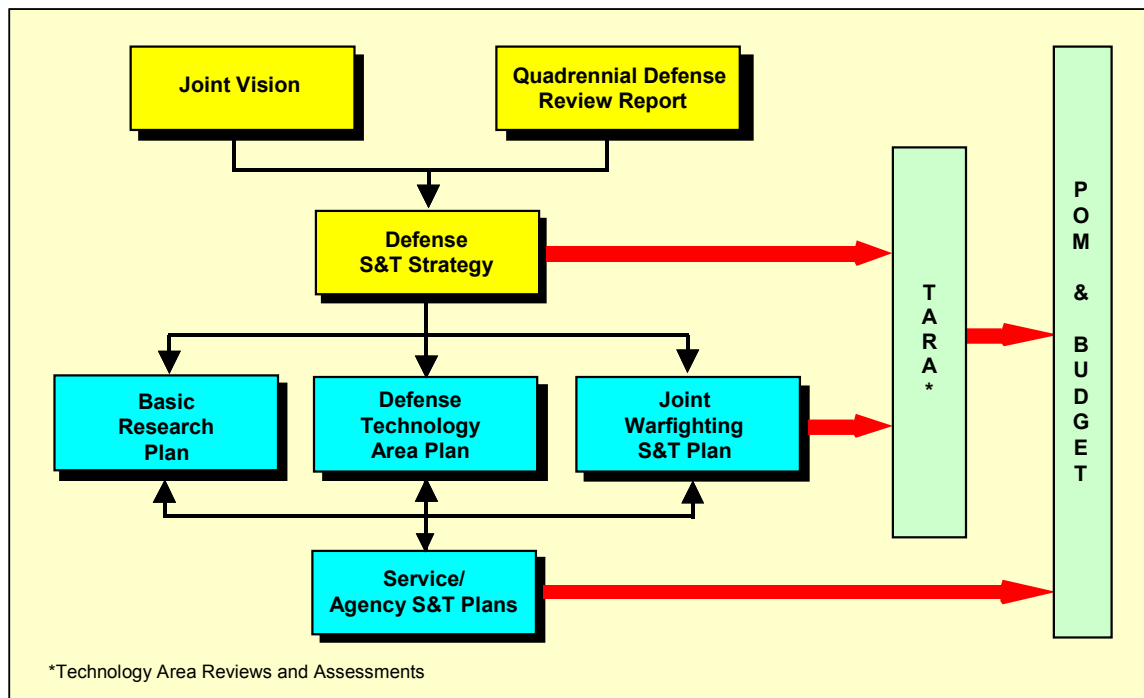
Technological superiority continues to be a cornerstone of our national military strategy. Technologies such as radar, jet engines, nuclear weapons, night vision, smart weapons, stealth, the Global Positioning System, unmanned air vehicles, and vastly more capable information management systems have changed warfare dramatically. Today's technological edge allows us to prevail across the broad spectrum of conflict decisively and with relatively low casualties. Maintaining this technological edge has become even more important as the size of U.S. forces decreases and as high-technology weapons are now readily available on the world market. In this new environment, it is imperative that U.S. forces possess technological superiority to achieve and maintain dominance across the full spectrum of crises and military operations. The technological advantage we enjoy today is a legacy of decades of investment in science and technology (S&T). Likewise, our future warfighting capabilities will be substantially determined by today's investment in S&T.

In peace, technological superiority is a key element of deterrence. In crisis, it provides a wide spectrum of options to the National Command Authorities and Combatant Commanders (CCs), while providing confidence to our allies. In war, it enhances combat effectiveness, reduces casualties, and minimizes equipment loss. In view of declining defense budgets and manpower reductions, advancing military technology and ensuring that it undergoes rapid transition to the warfighter are national security obligations of ever greater importance.

To fulfill these obligations, the Director of Defense Research and Engineering (DDR&E) has continued to enhance the strategic planning process for defense S&T. The foundation of this process is the *Defense Science and Technology Strategy* (Reference 1) with its supporting *Basic Research Plan* (BRP) (this document), *Joint Warfighting Science and Technology Plan* (JWSTP) (Reference 2), and *Defense Technology Area Plan* (DTAP) (Reference 3). These documents present the Department of Defense (DoD) S&T vision, strategy, plan, and objectives for the planners, programmers, and performers of defense S&T.

These documents are a collaborative product of the Office of the Secretary of Defense (OSD), Joint Staff, CCs, military services, and defense agencies. The strategy and plans are fully responsive to the Quadrennial Defense Review (QDR) Report (Reference 4) and the Chairman of the Joint Chiefs of Staff's *Joint Vision 2020* (Reference 5), as shown in Figure I-1. The strategy and plans and supporting individual S&T master plans of the military services and defense agencies guide the annual preparation of the defense program and budget. The strategy and plans are made available to the U.S. government and defense contractors, and our allies with the goal of better focusing our collective efforts on superior joint warfare capabilities and improving interoperability between the military services.

The Basic Research Plan presents the DoD objectives and investment strategy for DoD-sponsored Basic Research (6.1) performed by universities, industry, and service laboratories. In addition, it presents the planned investment in each of 12 technical disciplines composing the Basic Research Plan.



**Figure I-1. Science and Technology Planning Process**

The coupling of the BRP with the DTAP and the JWSTP is carried out in several ways. First, the planning stage of the 12 technical disciplines has the active participation of both the service laboratories and the warfighters (through the operating commands, such as the Army's Training and Doctrine Command (TRADOC)). This activity takes place by providing requirements and, sometimes, serving on planning committees that focus on or include basic research. Second, representatives of the service laboratories and operating commands also take part in the program evaluation process through attendance and participation in service S&T program reviews and the ODUSD(S&T) Technology Area Reviews and Assessments (TARAs).

#### **A. DEFENSE BASIC RESEARCH VISION**

The DoD Basic Research Program vision is to remain the preeminent S&T workforce providing fundamental scientific understanding that yields novel technical options and operational capabilities required for the defense of the United States.

#### **B. DEFENSE BASIC RESEARCH MISSION**

The Basic Research Program mission is to continue to conduct comprehensive basic research programs that will:

- Provide a strong foundation for new and future technologies required to support the mission of the Department of Defense by ensuring the availability of trained scientific manpower in technologies critical for national defense, and the necessary facilities in academia, industrial laboratories, and DoD establishments to perform advanced research.
- Assist in the development of revolutionary military capabilities and systems so that the U.S. military continues to be the best in the world, by providing a stream of basic

research results transitioning into applied research and advanced development to ensure that the best available technology reaches the warfighter in the shortest possible time.

- Keep DoD informed of worldwide technological developments and opportunities that might affect U.S. defense—for better or for worse—by focusing on technologies of critical importance to national defense, while maintaining a balanced research program ready to exploit unexpected opportunities or counter unforeseen technological threats.

## **C. UNDERSTANDING WARFIGHTER NEEDS**

The DoD *Defense Science and Technology Strategy* (Reference 1) emphasizes that the Defense Science and Technology Program must “ensure that the warfighters of today and tomorrow have superior and affordable technology to support their missions and provide revolutionary war-winning capabilities. To do this, we must understand the warfighters’ needs.” The Director of Defense Research and Engineering (DDR&E) oversees this strategy for the Secretary of Defense.

In today’s global environment, the U.S. military must dominate the full range of military operations—from humanitarian assistance to homeland defense and from counterterrorism to major theater warfare. The key to achieving this full-spectrum dominance is the ability to acquire information superiority and the enabling technologies. In addition, the key to warfighting success is the technologies that make our forces lighter, more mobile, and more lethal. Technological superiority is the principal characteristic of our military advantage.

The *Joint Warfighting Science and Technology Plan (JWSTP)* (Reference 2) identifies a broad range of future warfighting capabilities and objectives. The Defense S&T Program addresses these Joint Warfighting Capability Objectives (JWCOs) in basic research by focusing a significant portion of S&T investment in five areas: (1) information assurance, (2) battlespace awareness, (3) force protection, (4) reduced cost of ownership, and (5) maintaining a balanced basic research portfolio.

### **1. Information Assurance**

Information assurance remains a core research area for DoD. Research activities related to cyberterrorism and better protection for our critical information systems is a priority both on the battlefield and throughout the country.

### **2. Battlespace Awareness**

Battlespace awareness (situational awareness and understanding coupled with information assurance) is needed to provide real-time knowledge “from sensor to shooter.” In principle, smart sensor webs integrating networks of sensors with cognitive readiness systems will enable U.S. warfighters to exploit battlespace awareness. Basic research is needed to develop the foundations for real-time imagery with automatic target recognition capability. New physical models employing dynamic, intelligent databases are needed to enable real-time intelligence for the warfighter. The extremely large amount of information will require technical tools to help sort, mine, understand, and act in real time.

### **3. Force Protection**

The 21<sup>st</sup> century warfighter must have the capabilities to survive, fight, and win in a contaminated environment. Investments are needed in research and technology development to provide improved capabilities necessary to protect our forces against chemical and biological threats while minimizing adverse impacts on our warfighting capability.

### **4. Reduced Cost of Ownership**

An increased emphasis is being placed on affordability as a leading investment factor governing the S&T program. Research must be conducted to reduce the cost of operating and maintaining force readiness. One example is the research on improving combustion efficiency of mechanical energy generators and thereby reducing the operating, transportation systems, and associated logistics costs.

### **5. Maintaining a Balanced Basic Research Portfolio**

New military capabilities and operational concepts emerge from basic research. Basic research is a long-term investment with emphasis on opportunities for military applications far in the future. Furthermore, it contributes to our national academic and scientific knowledge base by providing substantial support for all science and engineering. Basic research investments over a long period of time have contributed significantly to new warfighter capabilities—low observables (stealth), lasers, infrared night vision, and microelectronics for precision strike, to name but a few. Many of these major advances were unpredictable. No promising avenue of research should be neglected. Although areas of emphasis may change, it is important to maintain a balanced portfolio in order to be prepared to deal with unforeseen developments anywhere in the world. Investments in defense basic research should help to prevent technological surprises by our adversaries.

Since most research applications require progress across several disciplines, an increased emphasis has been placed on multidisciplinary research activities. The Multidisciplinary University Research Initiative (MURI) program is a prime example of the approach to maintain a balanced research portfolio ([Chapter VII](#)). Another approach is building on current single disciplinary research areas by coordinating them into multidisciplinary efforts. The Strategic Research Areas ([Chapter VI](#)) focus attention on a few research areas that offer significant and comprehensive benefits to warfighting capabilities that will foster earlier warfighting applications than might not have been otherwise possible.

## **D. OBJECTIVES OF DEFENSE BASIC RESEARCH**

Defense basic research is focused in those fields of the physical, environmental, life, and engineering sciences appropriate to meeting long-term national security needs. Although often farsighted and risky, the research can have high payoffs in terms of future military systems. Defense basic research aims to serve as a catalyst to critical technologies that provide the basis for technological progress. As the results of defense basic research are transitioned, they support key military visions and concepts that provide new and improved military functions and capabilities.

Achieving these objectives in the coming decades requires that DoD's S&T programs:

- Maintain technological superiority in warfighting equipment and operations.

- Provide the knowledge basis for technical solutions that ensure opportunities for achieving breakthrough joint warfighting capabilities.
- Balance basic and applied research in pursuing technological advances.
- Incorporate affordability as a design parameter.

The *Quadrennial Defense Review Report* (QDR) (Reference 4) identifies six critical transformational capabilities:

- Protect bases of operation at home and abroad and defeat the threat of chemical, biological, radiological, nuclear, and explosive (CBRNE) weapons.
- Deny enemies sanctuary by providing persistent surveillance, tracking, and rapid engagement.
- Leverage information technology and innovative concepts to develop interoperable joint command, control, communications, computers, intelligence, surveillance, and reconnaissance (C<sup>4</sup>ISR) antiaccess capability.
- Project and sustain U.S. forces in distant antiaccess and area-denial environments.
- Enhance the capability and survivability of space systems.
- Ensure the survival of information systems in the face of attack and conduct effective information operations.

These six QDR capabilities have four transformational attributes:

- Knowledge
- Agility
- Speed
- Lethality.

*Joint Vision 2020* (Reference 5) explicitly defines the key military operational concepts for the 21<sup>st</sup> century as:

- Dominant maneuver
- Precision engagement
- Focused logistics
- Full-dimensional protection.

The services' visions are contained in the following documents:

- Army—*Army Vision 2020* (Reference 6)
- Air Force—*Global Engagement: A Vision for the 21st Century Air Force* (Reference 7) and the *Air Force Transformational Flight Plan, FY03–07* (Reference 8)
- Navy—*Forward...From the Sea—The Navy Operational Concept* (Reference 9) and *Navy Long Range Planning Objectives* (Reference 10)
- Marine Corps—*Operational Maneuver From the Sea* (Reference 11).

Taken together, these vision documents describe the concepts of operations and define the capabilities needed to meet the 21<sup>st</sup> century challenges. They establish the goals for DoD to achieve in the future and define the investment in science and technology. Basic research is a vital part of the S&T program, providing technological opportunities and fundamental understanding of processes and materials on which to base future military technologies.

Basic research is conducted in the context of the five overarching goals adopted by the Under Secretary of Defense for Acquisition, Technology and Logistics (USD (AT&L)):

- Achieve credibility and effectiveness in the acquisition and logistics support process.
- Revitalize the quality and morale of the DoD acquisition, technology, and logistics workforce.
- Improve the health of the defense industrial base.
- Rationalize the weapon systems and infrastructure with defense strategy.
- Initiate high-leverage technologies to create the warfighting capabilities, systems, and strategies of the future.

## **E. TRANSFORMATION INITIATIVES**

The Director of Defense Research and Engineering (DDR&E) has determined that, in response to the need to develop research programs supporting the critical QDR transformation initiatives, defense science and technology would focus efforts on three transformation enablers:

- *An integrated national framework for aerospace technologies.* This effort seeks to advance aerospace capabilities by emphasizing research and development in three major technology areas: hypersonic flight, access to space, and advanced space technologies. Key developments will include a supersonic/hypersonic missile; high-speed unmanned vehicles; long-range reconnaissance/strike aircraft; and access to lower cost, reusable space vehicles. This initiative will provide support for university and defense laboratory basic research programs that will advance basic understanding of fundamentals along with the support of engineering and science education in fields such as aerospace engineering, advanced materials, advanced energy and power, nanoscience, and other physical sciences.
- *Surveillance and knowledge systems.* This effort will focus on four technical thrust areas: sensors and unmanned vehicles, high-bandwidth communications and information assurance, information/knowledge management systems, and cyberwarfare.
- *Energy and power systems.* This effort will lead to significant reductions in the size and weight of platforms while improving performance. The primary focus will be on four technology areas: power generation, energy storage, power management and control, and directed energy. These areas should provide much greater capabilities to generate, store, and supply electrical and other forms of energy to nearly all air, ground, and sea platforms.

## **F. THE PAYOFF**

Technological breakthroughs and revolutionary military capabilities are difficult to predict from today's investments in basic research. In most cases, the full impact of scientific research does not become apparent until many years after its initiation. It is usually only in hindsight that one discerns the patterns of research that introduced the world to such revolutionary capabilities. However, we know that many of our current military capabilities and systems can be traced back to earlier basic research programs. Many payoffs to the Nation have occurred from timely DoD investments in basic research. Typical of the successes of research transitioned to actual systems in the field are the following:

- Global Positioning System
- Night vision technology
- Airborne Laser
- Internet and World Wide Web
- Satellite technology
- Stealth technology.

A brief description of each of these successes follows.

### **1. Global Positioning System**

Navies have always been concerned with precision navigation on a featureless ocean. The U.S. Navy, working through the Office of Naval Research (ONR), has supported basic research that led to an atomic clock (a hydrogen maser) with an accuracy corresponding eventually to a few feet in all three dimensions anywhere on earth.

The technology underlying the hydrogen maser clock relied on research from atomic spectroscopy studies supported by ONR. Later, advances in satellite technology, coupled with such ultra-precise atomic clocks, helped to provide precision location and navigation. The ONR-funded research, coupled with Air Force-supported research into coded transmission techniques, provided precise ranging and timing data anywhere on earth from a constellation of Global Positioning System (GPS) satellites. These satellites enabled the development of precision weapon delivery systems that can operate in all weather conditions and engage targets with an accuracy on the order of less than 1 meter. Steady investments in basic research over many years have been amply repaid by the superiority of our precision weapon systems. The GPS was a tremendous asset during both the Persian Gulf war and the Kosovo engagement. The civilian spinoff of GPS is well known.

### **2. Night Vision Technology**

The development of thermal imaging devices—based on long-term basic research in microelectronics, signal processing, and especially advanced materials—has permitted the U.S. Army to “own the night.” The original theoretical techniques were proposed in the 1950s. Basic research over a 30-year period into the science of semiconductor materials, metal-semiconductor interfaces and photoemission phenomena, and masers and lasers led to significant military capabilities to image targets at night. The successful use of thermal imaging systems in Desert Storm

vividly demonstrated the benefit of these systems, giving the U.S. forces a decided military advantage. This successful application provides ample justification for basic research investments made by the Army Research Office (ARO) to advance technology over a period of 35 years; moreover, it has now resulted in commercial and medical applications as well.

### **3. Airborne Laser**

The current Airborne Laser (ABL) program was enabled by basic research (supported by the Air Force Office of Scientific Research (AFOSR)) into laser beam generation techniques and propagation through the atmosphere. Successes in solving the atmospheric turbulence problem have revolutionized the ability to transmit laser beams through the atmosphere and have dramatically improved the ability of *ground-based* telescopes to obtain images of astronomical objects that rival those taken from space by the Hubble Space Telescope. Much of this work was initiated before definitive military requirements were established.

### **4. Internet and World Wide Web**

Another significant breakthrough was the initial development of the Internet by the Defense Advanced Research Projects Agency (DARPA). Many of the investments in basic computer science and technology led to the Advanced Research Projects Agency Network (ARPANet), which eventually evolved into the World Wide Web—impacting every aspect of civilian and military life. This modest DoD research investment has spawned an entire multi-billion-dollar information technology industry, which, in turn, has fueled the Nation's economy.

### **5. Satellite Technology**

DoD's early research into satellite technology and space systems has led to today's use of satellites for communications, navigation, and surveillance (including weather observations), thus making the United States more secure through rapid, worldwide communications, precision weapons, and valuable intelligence. Without the DoD investment, the space communications industry would have been slower to develop systems of direct benefit to the Nation's warfighters.

### **6. Stealth Technology**

AFOSR, DARPA, and other government agencies were instrumental in Dr. Joseph B. Keller's initial research on how light and radar are reflected by objects. In his effort to find the key to a better radar system, he brought about the development of mathematical formulas that formed the basis for the early research into low-observables technologies, or stealth. The design of the F-117 aircraft not only saves lives but also protects millions of dollars of technology and will continue to do so in future generations of aircraft.

## APPENDIX B: REFERENCES

1. *Defense Science and Technology Strategy*, Office of the Deputy Under Secretary of Defense (Science and Technology), May 2000
2. *Joint Warfighting Science and Technology Plan*, Office of the Deputy Under Secretary of Defense (Science and Technology), February 2003
3. *Defense Technology Area Plan*, Office of the Deputy Under Secretary of Defense (Science and Technology), February 2003
4. *Quadrennial Defense Review Report*, Department of Defense, September 30, 2001
5. *Joint Vision 2020*, Office of the Joint Chiefs of Staff, 2000 (available on the Internet at <http://www.dtic.mil/jv2020>)
6. *Army Vision 2020*, U.S. Army, February 2001
7. *Global Engagement: A Vision for the 21st Century Air Force*, U.S. Air Force, November 1998
8. *Air Force Transformational Flight Plan*, FY03–07, 2002
9. *Forward...From the Sea—The Navy Operational Concept*, U.S. Navy, March 1997
10. *Navy Long Range Planning Objectives*, Chief of Naval Operations, March 1998
11. *Operational Maneuver From the Sea*, U.S. Marine Corps Combat Development Command, August 1999
12. *National Security Science and Technology Strategy*, National Science and Technology Council, 1995
13. *Federal Funds for Research and Development: Fiscal Years 2000, 2001, and 2002*, National Science Foundation, Division of Science Resources Statistics, May 2002
14. *Federal R&D Funding by Budget Function: Fiscal Years 2001–03*, National Science Foundation, Division of Science Resources Statistics, NSF 02-330
15. *Defense Science and Engineering Research: Accomplishments of the DoD Multi-Disciplinary University Research Initiative, Legacy of the 1990's*, Foundation for the Future, April 17, 2002

## **APPENDIX A: PRINCIPAL POINTS OF CONTACT**

### **BASIC RESEARCH PANEL**

Dr. Lyle Schwartz , Chair  
Director  
Air Force Office of Scientific Research/CC  
4015 Wilson Boulevard, Room 908  
Arlington, Virginia 22203-1954  
Phone: (703) 696-7553  
Fax: (703) 696-9556  
e-mail: lyle.schwartz@afosr.af.mil

Dr. William O. Berry  
Director for Basic Sciences  
Office of the Undersecretary of Defense (LABS)  
4015 Wilson Boulevard, Suite 209  
Arlington, VA 22203  
Phone: (703) 696-0363  
Fax: (703) 696-0569  
e-mail: william.berry@osd.mil

Dr. James Murday  
Chief Scientist  
Office of Naval Research  
800 North Quincy Street  
Arlington, VA 22217-5660  
Phone: (703) 696-6783  
Fax: (703) 696-4065  
e-mail: james.murday@onr.navy.mil

Dr. Jim C. I. Chang  
Director  
Army Research Office  
P.O. Box 12211  
Research Triangle Park, NC 27709-2211  
Phone: (919) 549-4203  
Fax: (919) 549-4385  
e-mail: chang@aro.arl.army.mil

Dr. Barbara Sotirin  
Acting Director  
Army Research and Laboratory Management  
2511 Jefferson Davis Highway  
Arlington, VA 22202  
Phone: (703) 601-1544  
Fax: (703) 607-5989  
e-mail: barbara.sotirin@SAALT.army.mil

Dr. Robert Leheny  
Director, Microsystems Technology Office  
Defense Advanced Research Projects Agency  
3701 North Fairfax Drive  
Arlington, VA 22203-1744  
Phone: (703) 696-0048; (571) 218-4245  
Fax: (703) 696-2206  
e-mail: rleheny@darpa.mil

## **2002 Basic Research Review Panel**

Dr. Richard C. Powell  
Vice President for Research and Graduate Studies  
University of Arizona

Dr. Conilee G. Kirkpatrick  
Vice President  
Hughes Research Laboratories

Dr. Irene C. Peden  
Professor Emerita  
University of Washington, Electrical Engineering Department

Dr. Duane A. Adams  
Vice Provost for Research  
Carnegie Mellon University

Dr. John Dimmock  
Director, Center for Applied Optics  
University of Alabama at Huntsville

Dr. James R. Luyten  
Senior Associate Director and Director of Research  
Woods Hole Oceanographic Institution

Dr. Kathie Olsen  
Associate Director for Science  
Office of Science and Technology Policy

Dr. Frank Rose  
Former Director of Science, NASA Marshall Space Flight Center

Dr. Robert E. Roberts  
Vice President of Research  
Institute for Defense Analyses

Dr. Gerald Yonas  
Vice President and Principal Scientist  
Sandia National Laboratories

## **SCIENTIFIC PLANNING GROUPS**

### **Atmospheric and Space Sciences**

**Chair:** Major Paul Bellaire, Ph.D.  
 Program Manager, Space Sciences  
 Directorate of Mathematics & Space Sciences  
 Air Force Office of Scientific Research  
 4015 Wilson Boulevard, Room 823  
 Arlington, VA 22203-1954  
 Phone: (703) 696-8411  
 Fax: (703) 696-8450  
 e-mail: paul.bellaire@afosr.af.mil

Dr. Walter D. Bach, Jr.  
 Senior Program Manager  
 Mechanical & Environmental Sciences Division  
 Army Research Office  
 P.O. Box 12211  
 Research Triangle Park, NC 27709-2211  
 Phone: (919) 549-4247  
 Fax: (919) 549-4310  
 e-mail: bach@aro.arl.army.mil

Dr. Ronald Ferek  
 Program Officer, Marine Meteorology  
 Processes and Prediction Division  
 Office of Naval Research  
 800 North Quincy Street, Room 428-7  
 Arlington, VA 22217  
 Phone: (703) 696-0518  
 Fax: (703) 696-3390  
 e-mail: ronald\_ferek@onr.navy.mil

### **Biological Sciences**

**Chair:** Dr. Robert J. Campbell  
 Associate Director for Biological Sciences  
 Physical Sciences Directorate  
 Army Research Office  
 P.O. Box 12211  
 Research Triangle Park, NC 27709-2211  
 Phone: (919) 549-4250  
 Fax: (919) 549-4310  
 e-mail: campbell@aro.arl.army.mil

Dr. Walter Kozumbo  
 Program Manager  
 Directorate of Chemistry and Life Sciences  
 Air Force Office of Scientific Research  
 4015 Wilson Boulevard, Room 805  
 Arlington, VA 22203-1977  
 Phone: (703) 696-7720  
 Fax: (703) 696-8449  
 e-mail: walter.kozumbo@afosr.af.mil

Dr. Keith Ward  
 Biomolecular and Biosystems  
 Sciences and Technology Division  
 Office of Naval Research  
 800 North Quincy Street, Room 823  
 Arlington, VA 22217  
 Phone: (703) 696-0361  
 Fax: (703) 696-1212  
 e-mail: wardk@onr.navy.mil

## Chemistry

**Chair:** Dr. John Pazik  
Office of Naval Research  
800 North Quincy Street, Room 503  
Arlington, VA 22217  
Phone: (703) 696-4410  
Fax: (703) 696-6887  
e-mail: pazikj@onr.navy.mil

Dr. Douglas J. Kiserow  
Associate Director, Chemistry  
Physical Sciences Directorate  
Army Research Office  
P.O. Box 12211  
Research Triangle Park, NC 27709-2211  
Phone: (919) 549-4213  
Fax: (919) 549-4310  
e-mail: kiserow@aro.arl.army.mil

Dr. Michael Berman  
Program Manager  
Directorate of Chemistry and Life Sciences  
Air Force Office of Scientific Research  
4015 Wilson Boulevard, Room 803  
Arlington, VA 22203-1977  
Phone: (703) 696-7781  
Fax: (703) 696-8449  
e-mail: michael.berman@afosr.af.mil

## Cognitive and Neural Science

**Chair:** Dr. Paul A. Gade  
Chief, Research and Advance Concepts Office  
U.S. Army Research Institute (PERI-BR)  
5001 Eisenhower Avenue  
Alexandria, VA 22333-5600  
Voice: (703) 617-8866  
Fax: (703) 617-5162  
e-mail: gade@ari.army.mil

Dr. Willard S. Vaughan, Jr.  
Program Manager  
Office of Naval Research  
800 North Quincy Street  
Arlington, VA 22217  
Phone: (703) 696-4505  
Fax: (703) 617-1513  
e-mail: vaughaw@onr.navy.mil

Dr. Robert A. Sorkin  
Program Manager  
Directorate of Chemistry and Life Sciences  
Air Force Office of Scientific Research  
4015 Wilson Boulevard, Room 809  
Alexandria, VA 22203-1954  
Phone: (703) 696-8421  
Fax: (703) 696-8449  
e-mail: robert.sorkin@afosr.af.mil

## Electronics

**Chair:** Dr. William Clark  
Associate Director for Electronics  
Engineering Sciences Directorate  
Army Research Office  
P.O. Box 12211  
Research Triangle Park, NC 27709–2211  
Phone: (919) 549–4314  
Fax: (919) 549–4310  
e-mail: clarkww@aro.arl.army.mil

Dr. Gerald L. Witt  
Program Manager  
Directorate of Physics and Electronics Division  
Air Force Office of Scientific Research  
4015 Wilson Boulevard, Room 936  
Arlington, VA 22203–1977  
Phone: (703) 696–8571  
Fax: (703) 696–8481  
e-mail: gerald.witt@afosr.af.mil

Dr. Gerald M. Borsuk  
Superintendent  
Electronics Science & Technology Division  
Naval Research Laboratory  
4555 Overlook Avenue, SW  
Washington, DC 20575–5347  
Phone: (202) 767–3525  
Fax: (202) 767–3577  
e-mail: borsuk@estd.nrl.navy.mil

## Materials Science

**Chair:** Dr. Robert C. Pohanka  
Director  
Materials Science and Technology Division  
Office of Naval Research  
800 North Quincy Street  
Arlington, VA 22217  
Phone: (703) 696–4309  
Fax: (703) 696–0934  
e-mail: pohankr@onr.navy.mil

Dr. John Prater  
Associate Director for Materials Science  
Physical Sciences Directorate  
Army Research Office  
P.O. Box 12211  
Research Triangle Park, NC 27709–2211  
Phone: (919) 549–4259  
Fax: (919) 549–4310  
e-mail: prater@arl.aro.army.mil

Dr. Craig Hartley  
Director  
Directorate of Aerospace and Materials  
Air Force Office of Scientific Research  
4015 Wilson Boulevard, Room 837  
Arlington, VA 22203–1977  
Phone: (703) 696–8457  
Fax: (703) 696–8451  
e-mail: lyle.schwarz@afosr.af.mil

## Mathematics and Computer Sciences

**Chair:** Dr. Bruce West  
Senior Research Scientist  
Mathematical and Computer Sciences  
Army Research Office  
P.O. Box 12211  
Research Triangle Park, NC 27709–2211  
Phone: (919) 549–4257  
Fax (919) 549–4354  
e-mail: westb@aro.arl.army.mil

Dr. Robert Herklotz  
Program Manager  
Directorate of Mathematics and Space Sciences  
Air Force Office of Scientific Research  
4015 Wilson Boulevard, Room 820  
Arlington, VA 22203–1977  
Phone: (703) 696–6565  
Fax: (703) 696–8450  
e-mail: robert.herklotz@afosr.af.mil

Dr. Wen Masters  
Acting Director  
Mathematical, Computer, & Information  
Sciences Division  
Office of Naval Research  
800 North Quincy Street  
Arlington, VA 22217  
Phone: (703) 696–4312  
Fax: (703) 696–2611  
e-mail: wen\_masters@onr.navy.mil

## Mechanics

**Chair:** Dr. Richard Carlin  
Director  
Mechanics & Energy Conversion Science & Technology Division  
Engineering, Materials & Physical Sciences Department  
Office of Naval Research  
800 North Quincy Street, Room 507  
Arlington, VA 22217–5660  
Phone (703) 696–5075  
Fax: (703) 696–2558  
e-mail: richard\_carlin@onr.navy.mil

Dr. Julian M. Tishkoff  
Program Manager, Combustion and Diagnostics  
Directorate of Aerospace & Materials Sciences  
Air Force Office of Scientific Research  
4015 Wilson Boulevard, Room 842  
Arlington, VA 22203–1977  
Phone: (703) 696–8478  
Fax: (703) 696–8451  
e-mail: julian.tishkoff@afosr.af.mil

Dr. David M. Mann  
Associate Director for Engineering Sciences  
Engineering Sciences Directorate  
Army Research Office  
P.O. Box 12211  
Research Triangle Park, NC 27709–2211  
Phone: (919) 549–4249  
Fax: (919) 549–4310  
e-mail: dmann@aro.arl.army.mil

## Physics

**Chair:** Dr. Forrest J. Agee  
 Director  
 Directorate of Physics and Electronics  
 Air Force Office of Scientific Research  
 4015 Wilson Boulevard, Room 944  
 Arlington, VA 22203-1977  
 Phone: (703) 696-8570  
 Fax: (703) 696-8481  
 e-mail: jack.agee@afosr.af.mil

Dr. Michael F. Shlesinger  
 Chief Scientist  
 Physical Sciences S&T Division  
 Office of Naval Research  
 800 North Quincy Street  
 Arlington, VA 22217  
 Phone: (703) 696-4220  
 Fax: (703) 696-6887  
 e-mail: shlesim@onr.navy.mil

Dr. Henry Everitt  
 Associate Director for Physics  
 Physical Sciences Directorate  
 Army Research Office  
 P.O. Box 12211  
 Research Triangle Park, NC 27709-2211  
 Phone: (919) 549-4369  
 Fax: (919) 549-4310  
 e-mail: everitt@aro.arl.army.mil

## Terrestrial and Ocean Sciences

**Chair:** Dr. Steven Ackleson  
 Director  
 Processes and Predictions Division  
 Office of Naval Research  
 800 North Quincy Street  
 Arlington, VA 22217  
 Phone: (703) 696-4732  
 Fax: (703) 696-2007  
 e-mail: ackless@onr.navy.mil

Dr. Barbara J. Sotirin  
 Director  
 U.S. Army Engineer Research and  
 Development Center  
 Cold Regions Research and  
 Engineering Laboratory  
 U.S. Army Corps of Engineers  
 72 Lyme Road  
 Hanover, NH 03755  
 Phone: (603) 646-4201  
 Fax: (603) 646-4178  
 e-mail: barbara.j.sotirin@erdc.usace.army.mil

Dr. James H. Whitcomb  
 Head, Special Protects Section  
 Division of Earth Sciences  
 National Science Foundation  
 4201 Wilson Boulevard, #785  
 Arlington, VA 22230  
 Phone: (703) 292-8553  
 Fax: (703) 292-9025  
 email: jwhitcom@nsf.gov

Dr. Russell Harmon  
 Chief, Terrestrial Sciences Branch  
 Engineering Sciences Directorate  
 Army Research Office  
 P.O. Box 12211  
 Research Triangle Park, NC 27709-2211  
 Phone: (919) 549-4326  
 Fax: (919) 549-4354  
 e-mail: harmon@aro.arl.army.mil

## Scientific Research Area (SRA) Coordination Group 2002

Scientific Research Area	Army Representative	Navy Representative	Air Force Representative	DARPA Representative
<b>Bioengineering Sciences</b>	Dr. Robert Campbell Army Research Office P.O. Box 12211 Research Triangle Park, NC 27709-2211  Voice: (919) 549-4230 Fax: (919) 549-4310 campbell@aro.arl.army.mil	Dr. Harold Bright Office of Naval Research 800 North Quincy Street Code 342, BCT1, Rm. 823 Arlington, VA 22217  Voice: (703) 696-4054 Fax: (703) 696-1212 brighth@onr.navy.mil	Dr. Hugh De Long Air Force Office of Scientific Research 4015 Wilson Boulevard Arlington, VA 22203-1977  Voice: (703) 696-7722 Fax: (703) 696-8449 hugh.delong@afosr.af.mil	Dr. Alan Rudolph ( <b>Chair</b> ) Defense Advanced Research Projects Agency Defense Sciences Office 3701 North Fairfax Drive Arlington, VA 22203-1714  Voice: (703) 696-2240 Fax: (571) 218-4553 arudolph@darpa.mil
<b>Nanosciences</b>	Dr. William Mullins Army Research Office P.O. Box 12211 Research Triangle Park, NC 27709-2211  Voice: (919) 549-4286 Fax: (919) 549-4399 mullinsw@aro-emh1.army.mil	Dr. James S. Murday Naval Research Laboratory 4555 Overlook Avenue Building 207, Room 108 Washington, DC 20375  Voice: (202) 767-3026 Fax: (202) 404-7139 murday@ccf.nrl.navy.mil	Dr. Gernot Pomrenke ( <b>Chair</b> ) Air Force Office of Scientific Research 4015 Wilson Boulevard Arlington, VA 22203-1977  Voice: (703) 696-8426 Fax: (703) 696-8481 gernot.pomrenke@afosr.af.mil	
<b>Multifunction Materials</b>	Dr. John Prater ( <b>Chair</b> ) Army Research Office P.O. Box 12211 Research Triangle Park, NC 27709-2211  Voice: (919) 549-4259 Fax: (919) 549-4399 prater@aro.arl.army.mil	Dr. Roshdy Barsoum Office of Naval Research 800 North Quincy Street Code 334, BCT1, Room 528 Arlington, VA 22219  Voice: (703) 696-4306 Fax: (703) 696-0308 barsour@onr.navy.mil	Dr. Charles Lee Air Force Office of Scientific Research 4015 Wilson Boulevard Arlington, VA 22203-1977  Voice: (703) 696-7779 Fax: (703) 696-8449 charles.lee@afosr.af.mil	
<b>Information Dominance</b>	Dr. William Sander Army Research Office P.O. Box 12211 Research Triangle Park, NC 27709-2211  Voice: (919) 549-4241 Fax: (919) 549-4248 sander@aro.arl.army.mil	Dr. Wen Masters ( <b>Chair</b> ) Office of Naval Research 800 North Quincy Street Code 311, BCT1, Room 607 Arlington, VA 22219  Voice: (703) 696-4314 Fax: (703) 696-2611 wen_masters@onr.navy.mil	Dr. John Sjogren Air Force Office of Scientific Research 4015 Wilson Boulevard Arlington, VA 22203-1977  Voice: (703) 696-6564 Fax: (703) 696-8450 jon.sjogren@afosr.af.mil	
<b>Human Performance Sciences</b>	Dr. Paul Gade ( <b>Chair</b> ) ARI (PERI-BR) 5001 Eisenhower Avenue Alexandria, VA 22333-5600  Voice: (703) 617-8866 Fax: (703) 617-5162 gade@ari.army.mil	Dr. Willard Vaughan Office of Naval Research 800 North Quincy Street Code 342, BCT1, Room 823 Arlington, VA 22219  Voice: (703) 696-4505 Fax: (703) 696-1212 vaughaw@onr.navy.mil	Dr. Robert D. Sorkin Air Force Office of Scientific Research 4015 Wilson Boulevard Arlington, VA 22203-1977  Voice: (703) 696-8421 Fax: (703) 696-8449 robert.sorkin@afosr.af.mil	
<b>Propulsion and Energetic Sciences</b>	Dr. Richard Paur Army Research Office P.O. Box 12211 Research Triangle Park, NC 27709-2211  Voice: (919) 549-4208 Fax: (919) 549-4354 paur@aro.arl.army.mil	Dr. Richard Carlin ( <b>Chair</b> ) Office of Naval Research 800 North Quincy Street Code 333, BCT1, Room 507 Arlington, VA 22219  Voice: (703) 696-5075 Fax: (703) 696-2558 richard_carlin@onr.navy.mil	Lt. Col. Paul Trulove Air Force Office of Scientific Research 4015 Wilson Boulevard Arlington, VA 22203-1977  Voice: (703) 696-7787 Fax: (703) 696-8449 paul.trulove@afosr.af.mil	

## **NON-DOD GOVERNMENT AGENCIES** **SPG REVIEW PANELISTS**

### **Atmospheric and Space Sciences**

Dr. Richard Behnke  
Section Head, Upper Atmosphere Section  
National Science Foundation  
4201 Wilson Boulevard, Room 775.17  
Arlington, Virginia 22230  
Phone: (703) 292-4694  
Fax: (703) 292-9022  
rbehnke@nsf.gov

Dr. Richard Vondrak  
National Aeronautics and Space Administration  
richard.vondrak@gsfc.nasa.gov

Dr. David Rogers  
Chief Scientist  
National Oceanic and Atmospheric Administration  
david.rogers@noaa.gov

### **Biological Sciences**

Dr. Frank C. Greene  
Division Director  
Integrative Biology & Neurosciences  
National Science Foundation  
4201 Wilson Boulevard, Room 685  
Arlington, Virginia 22230  
Phone: (703) 292-8420  
Fax: (703) 292-9153  
fgreene@nsf.gov

Dr. Joe Bielitzki  
National Aeronautics and Space Administration  
jbielitzki@darpa.gov

Dr. Michael Marron  
Director, Division of Biomedical Technology  
National Center for Research Resources  
National Institutes of Health  
6705 Rockledge Drive  
Bethesda, MD 20892-7965  
Phone: (301) 435-0755  
Fax: (301) 480-3659  
marron@nih.gov

### **Chemistry**

Dr. Francis J. Wodarczyk  
Program Director  
Theoretical and Computational Chemistry  
National Science Foundation  
4201 Wilson Boulevard, Room 1055  
Arlington, Virginia 22230  
Phone: (703) 292-8840  
Fax: (703) 292-9037  
fwodarcz@nsf.gov

Dr. Stephen Rodgers  
Manager  
Propulsion Research Center  
Marshall Space Flight Center  
Mail Stop TD40, Bldg. 4203, Room 2101  
Huntsville, Alabama 35812  
Phone: (256) 544-0818  
Fax: (256) 544-5926  
stephen.rodgers@msfc.nasa.gov

Dr. Jerry J. Smith  
Department of Energy  
jerry.smith@science.doe.gov

Dr. Eric Amis  
National Institute of Standards and Technology  
eric.amis@nist.gov

## Cognitive and Neural Sciences

Dr. Guy Van Orden  
Program Director  
Human Cognition and Perception  
National Science Foundation  
4201 Wilson Boulevard, Room 995  
Arlington, Virginia 22230  
Phone: (703) 292-8732  
Fax: (703) 292-9068  
gvanorde@nsf.gov

Dr. Dennis L. Glanzman  
Chief, Theoretical & Computational  
Neuroscience Program  
National Institute of Health, DHHS  
6001 Executive Boulevard, Room 7171  
Bethesda, Maryland 20892-9637  
Phone: (301) 443-1576  
Fax: (301) 443-4822  
glanzman@helix.nih.gov

## Electronics

Dr. James Mink  
Program Director  
Electrical and Communication Systems  
National Science Foundation  
4201 Wilson Boulevard, Room 675  
Arlington, Virginia 22230  
Phone: (703) 292-8339  
Fax: (703) 292-9147  
jmink@nsf.gov

Dr. Thycodam V. George  
Program Manager  
Office of Fusion Energy Science  
Department of Energy  
Washington, DC  
Phone: (301) 903-4957  
Fax: (301) 903-1233  
tv.george@science.doe.gov

Dr. James Olthoff  
National Institute of Standards  
and Technology  
james.olthoff@nist.gov

Dr. Elizabeth Kolawa  
Manager  
Advanced Measurements and Detection  
Office  
Jet Propulsion Laboratory  
California Institute of Technology  
4800 Oak Grove Drive, Mail Stop 180-603  
Pasadena, CA 91109-8099  
Phone: (818) 393-2593  
Fax: (818) 393-5269  
elizabeth.kolawa@jpl.nasa.gov

## Materials Science

Dr. LaVerne D. Hess  
Program Director  
National Science Foundation  
4201 Wilson Boulevard, Room 1065  
Arlington, Virginia 22230  
Phone: (703) 292-4937  
Fax: (703) 292-9035  
Tweber@nsf.gov

Dr. Michael Wargo  
National Aeronautics and Space Administration  
mwargo@hq.nasa.gov

Dr. Michael Kassner  
Department of Energy  
kassner@engr.orst.edu and  
michael.kassner@science.doe.gov

Dr. Richard Fields  
National Institute of Standards and Technology  
richard.fields@nist.gov

## Mathematics and Computer Science

Dr. Deborah Lockhart  
Cluster Coordinator  
Applied Math Program  
National Science Foundation  
dlockhar@nsf.gov

Dr. Geoffrey McFadden  
National Institute of Science and  
Technology (NIST–Math)  
geoffrey.mcfadden@nist.gov

Dr. Michael Shneier  
National Institute of Science and  
Technology (NIST–CS)  
michael.shneier@nist.gov

Dr. Daniel A. Hitchcock  
Senior Technical Advisor for Advanced  
Scientific Computing Research  
Department of Energy  
Mail Stop SC-30  
Washington, DC 20585  
Phone: (301) 903–6767  
Fax: (301) 903–4846  
daniel.hitchcock@science.doe.gov

## Mechanics

Dr. Tony Chen  
Program Director  
Fluid Dynamics and Hydraulics  
NSF  
cchen@nsf.gov

Dr. Michael M. Reischman  
Director  
University Program  
NASA Headquarters  
300 E Street, SW  
Washington, DC 20546  
Phone: (202) 358–2098  
Fax: (202) 358–2920  
reischm@hq.nasa.gov

Dr. Arthur C. Ratzel  
Group Manager  
Thermal, Fluids, and Aero Sciences  
Sandia National Laboratories  
Mail Stop 0824  
P.O. Box 5800  
Albuquerque, NM 87185  
Phone: (505) 844–0824  
Fax: (505) 844–4523  
acratze@sandia.gov

## Ocean and Terrestrial

### Ocean

Dr. David Garrison  
Associate Program Director  
Division of Ocean Sciences  
NSF  
dgarrison@nsf.gov

Dr. Susan Banahan  
Program Manager  
Coastal Ocean Program, N/SC12  
National Oceanic and Atmospheric  
Administration  
1305 East West Highway, Room 8205  
Silver Spring, MD 20910  
Phone: (301) 713–3338, x148  
Fax (301) 713–4044  
susan.banahan@noaa.gov

Dr. Marie Colton  
National Oceanic and Atmospheric  
Administration  
marie.colton@noaa.gov

Dr. Mary Jo Baedecker  
U.S. Geological Survey  
mjbaedec@usgs.gov

## **Terrestrial**

Dr. James Whitcomb  
National Science Foundation  
jwhitcom@nsf.gov

Dr. Eric J. Lindstrom  
Oceanography Program Scientist  
NASA Headquarters, Code YS  
300 E Street NW, Room 5L82  
Washington, DC 20546  
Phone: (202) 358-4540  
Fax: (202) 358-2770  
elindstr@hq.nasa.gov

## **Physics**

Dr. Joseph Dehmer  
Director  
Division of Physics  
National Science Foundation  
jdehmer@nsf.gov

Dr. Robert Colotta  
National Institute of Science and Technology  
robert.colotta@nist.gov

Dr. Eric A. Rohlfig  
Chemical Sciences  
Geosciences & Biosciences Division  
Office of Basic Energy Sciences  
Department of Energy  
1000 Independence Avenue, SW  
Washington, DC 20585-1290  
Phone: (301) 903-8165  
Fax: (301) 903-4110  
eric.rohlfig@science.doe.gov

Dr. Lute Maleki  
Senior Research Scientist & Group  
Supervisor  
Jet Propulsion Laboratory, NASA  
Mail Stop 298-100  
4800 Oak Grove Drive  
Pasadena, California 91009  
Phone: (818) 254-3688  
Fax: (818) 292-6773  
lute.maleki@jpl.nasa.gov

## **PREPARATION TEAM**

**Chair:** Dr. Kenneth E. Harwell  
Senior Science Advisor to the  
Director of Basic Research  
Office of Deputy Under Secretary of  
Defense for Laboratories and Basic Sciences  
Director, Defense Research and Engineering,  
Department of Defense  
4015 Wilson Boulevard, Room 216  
Arlington, Virginia 22203-1954  
Phone: (703) 696-2533  
Fax: (703) 696-2535  
kenneth.harwell@osd.mil

Dr. Marta Kowalczyk  
Institute for Defense Analyses  
Science & Technology Division  
4850 Mark Center Drive  
Alexandria, Virginia 22311  
Phone: (703) 578-2862  
Fax: (703) 578-2877  
marta.kowalczyk@osd.mil

Mr. Ron Shamblin  
Contractor  
Air Force Office of Scientific Research  
4015 Wilson Boulevard, Room 729  
Arlington, Virginia 22203-1954  
Phone: (703) 588-2163  
Fax: (703) 696-8479

Dr. Cliff Lau  
Associate Director for Corporate  
Programs  
Office of Naval Research  
800 North Quincy Street  
Arlington, Virginia 22217-5660  
Phone: (703) 696-0431  
Fax: (703) 588-1013  
lauc@onr.navy.mil

Ms. Cecelia Handy  
Contractor  
Air Force Office of Scientific Research  
4015 Wilson Boulevard, Suite 728  
Arlington, Virginia 22203-1954  
Phone: (703) 696-1086  
Fax: (703) 696-8479  
cecelia.handy@afosr.af.mil

## **CHAPTER VIII**

### **BASIC RESEARCH SUCCESS STORIES**

As outlined in the previous chapters, each of the military services has a significant investment in basic research. The outcome of this investment is the development of new technology for military systems.

For the most part, the commercial market would not have developed this technology without military underwriting. In some cases, the risk associated with the technology was too high to demonstrate to investors significant progress toward commercialization in a short time period. In other cases, the technology would be applied to only a few systems and would not have developed into a large commercial market; therefore, it was not appealing for development by industry. In still other cases, the technology supported a unique military niche, and although it was very valuable for certain military applications and could have led to insertion in large numbers of systems, commercial applications were rare.

This chapter outlines a collection of recent basic research topics that have been applied successfully to address military problems. In some of the examples, the work has been transitioned successfully and is now being inserted into military systems. Some of the other examples show research that has extraordinary promise to improve systems but still needs additional work before the technology is ready for insertion. Each technology development discussed here covers one page, stating what was accomplished and why it was important for the military. This format was used in another recent publication (Reference 15) that focused on the OSD Multidisciplinary University Research Initiative (MURI) success stories. Here the focus is broader, covering the entire Basic Research Program.

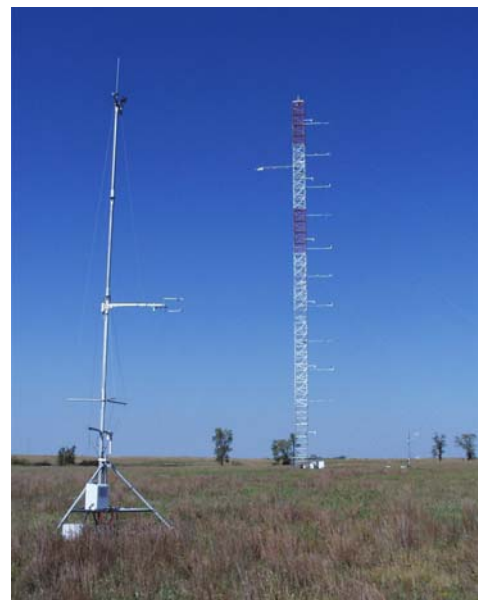
## *ATMOSPHERIC AND SPACE SCIENCES: ARMY I STABLE BOUNDARY LAYERS*

### *SUMMARY*

Scientists from seven universities, five federal laboratories, and small business developed and executed a comprehensive field study of the nocturnal atmospheric boundary layer (NABL) to develop new theory and understanding of those processes.

### *WHAT WAS ACCOMPLISHED*

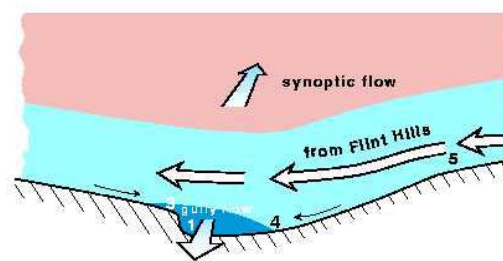
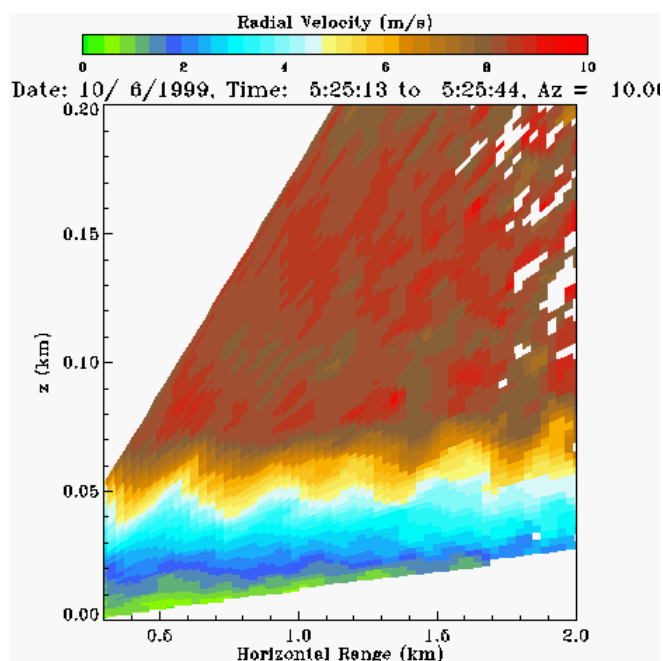
The seminal database for the evolution of the four-dimensional NABL was developed during October 1999 in central Kansas. Multiple fixed towers, aircraft, radars, LIDARs, balloons, and kites were used to measure relevant atmospheric variables within the first kilometer of the air.



*60-m instrumented tower at the field site*

### *WHY IT IS IMPORTANT*

The NABL is the least understood and least predictable part of the atmosphere. Forecast models are inappropriate for describing the intermittent turbulent events that occur here. Yet, nighttime is the preferred environment for ground-based military operations. The NABL is the preferred medium for air dispersal of toxic agents. Fundamental, observation-based knowledge is required to develop better theories and models. Observations and research analyses are showing a wide variety of unexpected processes and a new look at the NABL. New theories and parameterizations are being developed to provide a significantly improved representation of NABL conditions and processes.



*Above: Tri-directional flow in a shallow gully  
Left: Shear instability below a low-level jet using a Doppler LIDAR system*

## *ATMOSPHERIC AND SPACE SCIENCES: ARMY 2*

### *BIOCHEM DETECTOR USES ATMOSPHERIC LASER TRANSMISSION*

#### *SUMMARY*

Researchers from Fibertek Inc. in Herndon, Virginia, and the Army's Chemical and Biological Defense Command (CBDC) at Aberdeen Proving Ground, Maryland, demonstrated a multiwavelength LIDAR system with biochemical detection capabilities between 310 and 445 nm.

#### *WHAT WAS ACCOMPLISHED*

The system features two ultraviolet (UV) lasers and an infrared (IR) laser that cause fluorescence in biological agents, along with a telescope/receiver assembly for detection. The optical system can detect toxins up to 3 km away, with proper forecast of atmospheric propagation effects.

#### *WHY IT IS IMPORTANT*

The U.S. Army has field-tested a LIDAR system that could provide the first line of defense in the event of an attack from biochemical agents dispersed in the atmosphere.



## *ATMOSPHERIC AND SPACE SCIENCES: AIR FORCE & NAVY I CORIOLIS MISSION PAYLOADS READY FOR FLIGHT*

### *SUMMARY*

Coriolis is a test mission for the flight of two DoD payloads for the Air Force and Navy. Spectrum Astro in Gilbert, Arizona, is the prime contractor for the spacecraft bus. The two Coriolis payloads will collect data continuously during a 3-year mission. The Coriolis spacecraft is scheduled to launch aboard a Titan II rocket from Vandenberg AFB, California, in early 2003.



### *WHAT WAS ACCOMPLISHED*

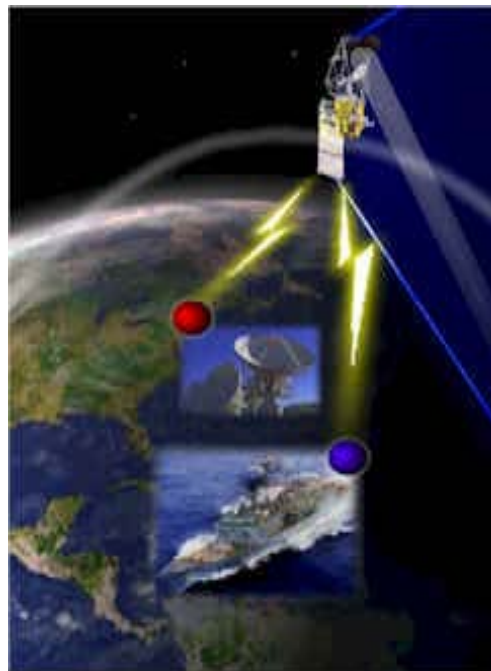
Two payloads have been constructed for orbital flight: the Navy's WindSat payload, a polarimetric microwave radiometer experiment to passively measure the ocean surface wind vector; and the Air Force Research Laboratory's Solar Mass Ejection Imager (SMEI), a device designed to monitor solar activity with the goal of more accurately predicting geomagnetic disturbances to orbiting satellites.

### *WHY IT IS IMPORTANT*

An important element of WindSat is the accurate measurement of ocean wind vectors (wind speed and direction). Many elements of the Navy fleet consider wind speed and direction the most useful weather intelligence. Accurate wind vector data affect a broad range of naval missions, including strategic ship movement and positioning, aircraft carrier operations, aircraft deployment, effective weapon use, underway replenishment, and littoral operations.

SMEI will image the space environment using baffled camera components with charge-coupled device (CCD) sensors. Both the nominal and disturbed space environment can disrupt the detection and tracking of aircraft, missiles, satellites, and other targets; distort communications and navigation; and interfere with global command, control, and surveillance operations. By tracking coronal mass ejections from the Sun to the Earth, SMEI will make possible accurate 24- to 72-hour forecasts of the solar storms that impact DoD space systems.

WindSat and SMEI will thus aid in developing short-term forecasts, issuing timely warnings, and gathering general environmental data.



## *ATMOSPHERIC AND SPACE SCIENCES: AIR FORCE & NAVY 2*

### *CCMC TRANSITIONS MODELS TO SPACE WEATHER FORECASTING RAPID PROTOTYPING CENTER*

#### *SUMMARY*

The Community Coordinated Modeling Center (CCMC) fills a longstanding gap between the space weather research community and the operational arms of the National Oceanic and Atmospheric Administration (NOAA) and DoD responsible for providing space weather services to a large customer base. At the present time, both NOAA and DoD are creating Rapid Prototyping Centers (RPCs) that implement space weather models at their respective operational centers in Boulder and Colorado Springs. CCMC's goal is to facilitate the development, validation, and test of space weather models, which can eventually be transferred to the RPCs to adapt for operational use. The CCMC will provide computer assets sufficient for the development and test of the largest and most sophisticated space weather models. CCMC staff will support the integration of existing research grade models, as well as perform research in space plasma physics, as required, to further space weather goals. For these purposes, it will contain scientific and technical personnel, as well as realistic databases, to efficiently develop and exercise the models as well as to prepare them for transitioning.

#### *WHAT WAS ACCOMPLISHED*

The University of Michigan's BATSRUS magnetospheric model has been validated and enhanced, and is now at the USAF space weather RPC at SMC/CISF, Detachment 11, Peterson AFB, in Colorado Springs. The model has received rave reviews during operational testing. HQ USAF/XOW has commended the innovative interagency partnership that made this transition possible.

#### *WHY IT IS IMPORTANT*

By helping create better models of the space environment from the Sun to the Earth, the CCMC makes possible accurate forecasts of geomagnetic storms that impact DoD space systems. Modelers benefit from the knowledge and expertise of CCMC staff, who provide the necessary feedback for rapid improvement of models. The staff communicates with NOAA and DoD users to ensure that operational needs are being met. The CCMC's goal is that scientific models will eventually be used at one of the forecast centers instead of remaining perpetually in "research mode," accelerating the transition of DoD investments to the warfighter.



*BIOLOGY: ARMY (ARMY MEDICAL RESEARCH AND MATERIEL COMMAND)*  
*PREVENTION OF ALTITUDE-INDUCED INJURY AND PERFORMANCE DEGRADATION*

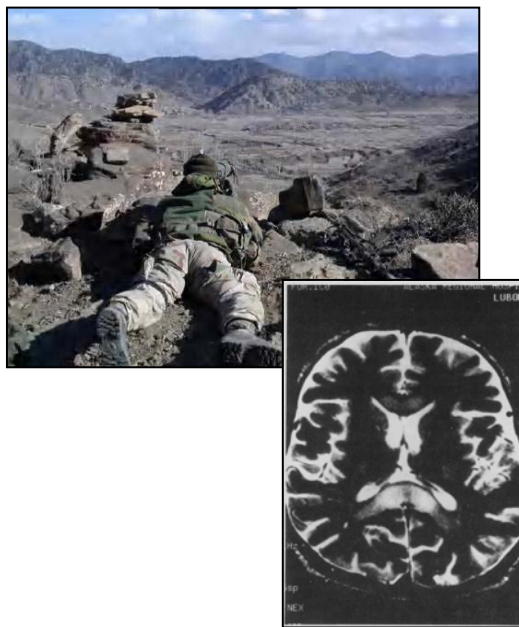
*SUMMARY*

Information gained through altitude research at the U.S. Army Research Institute of Environmental Medicine (USARIEM) is having a significant impact on the warfighting capabilities of soldiers currently deployed to Afghanistan.

*WHAT WAS ACCOMPLISHED*

The U.S. Army Medical Research Materiel Command's Military Operational Medicine Research Program invests in basic research on sustaining soldier performance and preventing injuries in operations at altitude. Some of the world's leading experts in the field perform this research at USARIEM.

USARIEM provided critical information to units deploying to Afghanistan on preventing injury and performance decrements in operations at altitude. The information included instructions for staging and intermittent hypoxia exposure to induce altitude acclimatization, physiological indicators to assess altitude acclimatization, tables relating expected performance decrements and expected altitude sickness and severity, and procedures for avoiding and treating altitude sickness. USARIEM captured the information in the following series of information papers that they widely distributed to deploying units: *Assessing Individual Altitude Acclimatization Status*; *Staging Protocols for Inducing Altitude Acclimatization*; *Altitude Acclimatization Induced by Intermittent Hypoxia Exposure*; *Estimating Performance Decrements at Altitude*; *Estimating Altitude-Induced Illness Incidence and Severity*; *Prevention and Treatment of Altitude Illness*; *Medications Contraindicated in High Altitude Deployments*; and *Review of US Army Medical Materiel Development Activity Pharmaceutical Products in High Altitude*. The U.S. Army Center for Health Promotion and Preventive Medicine also included this information in their Technical Guide Number 274, *A Guide to Acclimatization, Illness & Physical Work Performance at High Altitude*.



*Top: Special Forces in mountains of Afghanistan, February 2002*  
*Above: Weighted MRI of a mountain climber with high-altitude edema during acute illness*  
 (Source: PH Hackett, Hypoxia, p.32, Plenum Press, New York, 1999)

*WHY IT IS IMPORTANT*

During rapid deployment to high-altitude environments, such as those in Afghanistan, soldiers face the risk of injury and illness, including acute mountain sickness, high-altitude pulmonary edema, and cerebral edema. The information provided through Army altitude research maintains soldier health and prevents performance decrements that could prevent soldiers from accomplishing their mission.

## *BIOLOGY: ARMY (ARO)*

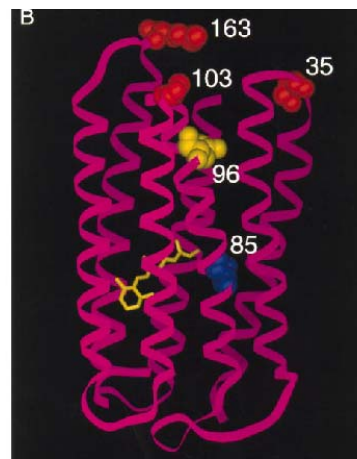
### *BIOMOLECULAR MATERIALS FOR SENSORS, INFORMATION PROCESSING, AND SIGNATURE REDUCTION*

#### *SUMMARY*

ARO-sponsored research on genetic engineering of bacteriorhodopsin (bR) at Wayne State University has enabled technology development for storing information in biologically derived molecules.

#### *WHAT WAS ACCOMPLISHED*

Biomolecular materials derived from photodynamic proteins promise to have superior photochromic, optoelectronic, or nonlinear optical characteristics useful for application in advanced devices and coatings. For example, through genetic engineering, a family of proteins based on bR has been shown to have novel properties of interest to the sensor, optoelectronics, and information storage research communities, particularly in integrated spin-polarized and bR-based optical devices and holographic memory storage. For the latter, the greatest density storage that could be realized would be to use a single molecule for storing a bit. In an attempt to improve the behavior of bR as a storage material, research supported in the ARO Life Sciences Division used a genetically based approach for developing bR mutants with resultant alterations in various amino acid residues. The changes chosen were based on rational analysis and on random changes. The rational analysis relied on a new high-resolution crystal structure of bR and on experiments on the mechanism of proton transfer by wild-type bR.

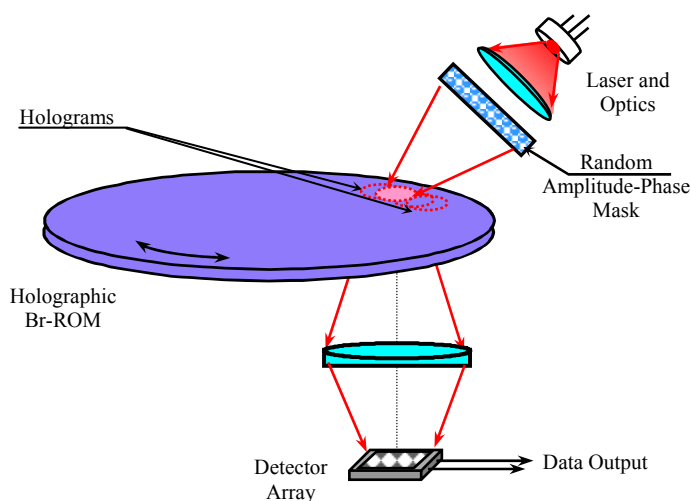


#### *WHY IT IS IMPORTANT*

Some of these mutants have been incorporated into a high-storage-density-volume memory device compatible with current drives and into commercially fielded devices that have been used by the military to process information (e.g., in wind-tunnel diagnostic analyses).

*Top right: Research on genetic engineering of light-activated protein bR has enabled the development of novel and greatly improved holographic and other optical and device-related materials.*

*Right: Ultra-high-capacity holographic memory using Bacteriorhodopsin (bR)*



## *BIOLOGY: AIR FORCE (AFOSR) ULTRASHORT LASER BIOEFFECTS TEAM*

### *SUMMARY*

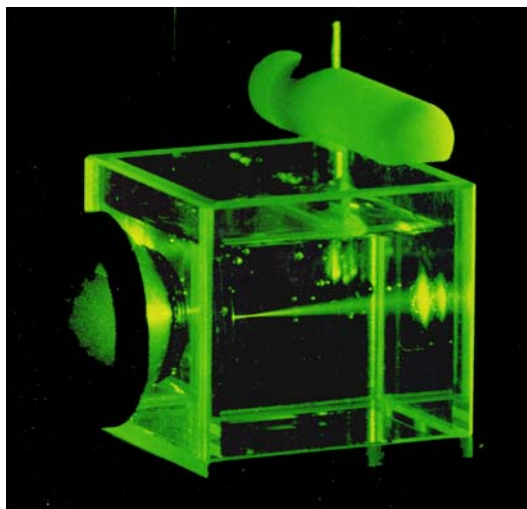
Over the past decade, basic research conducted by the Air Force and its university collaborators has determined the threshold levels at which ocular exposures to short-pulsed (subnanoseconds in duration) laser light would produce retinal damage. Biological databases were developed and other basic research was performed to demonstrate that nonlinear physical mechanisms were at least partly responsible for producing lesions on retinas exposed to these extremely short pulses of laser light. Information obtained from this research has played an important role in setting new national, international, and military laser safety standards in 2001, enabling the development of appropriate operational concepts for laser weapon systems. These laser safety standards also provide a scientific basis for validating future models that are capable of predicting ocular damage from exposures to new generations of military lasers.

### *WHAT WAS ACCOMPLISHED*

The AFOSR Ultrashort Laser Bioeffects Program has transitioned important models of laser-induced biological damage that will enhance the warfighter's ability to assess mission impact in the laser-rich battlefield of the future. Mission impact assessment requires a fundamental understanding of how laser light, at various wavelengths and pulse durations, would induce tissue damage in the eye. For exposures to pulses between 100 femtoseconds and 10 microseconds, for example, one such mechanism of retinal damage was discovered to involve the formation of microbubbles around the light-absorbing melanin granules of the retina. Air Force researchers and university collaborators not only described this phenomenon but were also able to build models of microbubble creation around highly absorbing nanoparticles. These models have been subsequently transitioned into an international effort, involving the military of the United States and the United Kingdom, to determine damage thresholds to eyes behind advanced limiter devices (e.g., advanced agile laser eye protection).

### *WHY IT IS IMPORTANT*

The goal of this project is to determine the effectiveness of various nonlinear optical limiters as laser eye protection for pulsed laser systems. Ultimately, the outcome of such an effort will dramatically affect the battlefield commander's ability to assess potential aircrew flythroughs or flight-mission cancellation when laser threats are recognized.



*The artificial eye developed by AFRL/HEDO allows for investigation of nonlinear optical effects that influence retinal damage from accidental laser exposure.*

## CHEMISTRY: ARMY (ARO 1)

### DECADE OF DoD RESEARCH LEADS TO NEW DEMILITARIZATION TECHNOLOGY

#### SUMMARY

Above the critical point of water ( $373^{\circ}\text{C}$ ), even complex organic substances are soluble. Adding a source of oxygen causes organics to be quickly oxidized to small molecules. This process, Supercritical Water Oxidation (SCWO), has been developed by the Army and Navy for destruction of toxic military materials. These military programs provide most of the Nation's R&D for disposal of toxic materials.

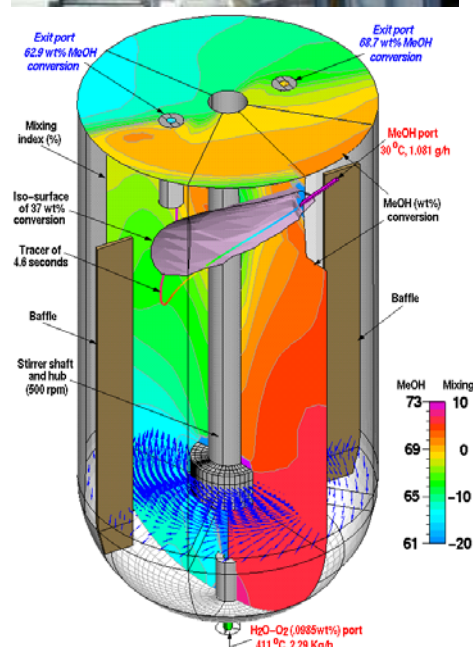
#### WHAT WAS ACCOMPLISHED

In 1988, a joint ARO and ONR workshop on "DoD Applications for Supercritical Fluids" recommended research on SCWO. A research plan was developed at an ARO/NATO meeting in 1990, and in 1992 the Army, with DoD funds, supported three large university centers at Delaware, Texas–Austin, and MIT to develop the fundamental understanding required to design and operate reactors for treatment of military toxic wastes—principally chemical weapon agents and explosives. The Navy, through a DARPA program, supported design and construction of SCWO units for shipboard use.

Army basic research has addressed all aspects of the problem, ranging from rates of chemical reactions to corrosion of reactor materials. In the late 1990s, the Army chose SCWO for treatment of nerve agent, explosives, and other toxic organic military materials. Systems are now being constructed and tested at Newport, Indiana, and Pine Bluff, Arkansas. In 1998, the Army Small-Business Innovative Research (SBIR) program supported development of computer models of the SCWO process. These models incorporate the results of basic research and enable the efficient design and optimum operation of reactors.

#### WHY IT IS IMPORTANT

At times, toxic substances are by-products of military materiel development and operations. The capability to convert toxic materials to inert ones has a tremendous impact for the environment in which the military operates. Such capability also has enormous impact for commercial industry.



*Top: Downflow SCWO pilot-scale test reactor to support the Army Chemical Weapon Demilitarization facility at Newport, Indiana*

*Above: Computational Fluid Dynamics and Reaction Kinetics Simulator can model complex systems. Colors show degree of mixing of methanol in H<sub>2</sub>O/O<sub>2</sub> in stirred tank reactor. Simulations are checked against experimental data.*

*(Source: CFD Corp; OLI Systems, MIT Collaboration)*

## *CHEMISTRY: ARMY (ARO 2)*

### *REACTIVE NANOPARTICLES FOR NEUTRALIZATION OF TOXIC CHEMICALS*

#### *SUMMARY*

Over 15 years ago, ARO sponsored its first work at Kansas State University that eventually led to the development of reactive nanoparticles (RNPs) that react with toxic chemicals and biological agents.

#### *WHAT WAS ACCOMPLISHED*

In 1985, this work focused on the interaction of metal oxide surfaces with organophosphorous compounds. In 1990 it led to the discovery of a process to prepare nanoparticles of magnesium oxide (MgO) and the study of their enhanced reactivity. Further work with the laboratories of the Army Materiel Command and Air Force is ongoing to confirm the fundamental chemistry of the reactive nanoparticles with toxic chemical and biological agents. The reactive nanoparticles are currently being evaluated by the Soldier Biological and Chemical Command for use in protective clothing, protective skin creams, sample concentrators, and reactive sorbents and filter materials for the soldier.

#### *WHY IT IS IMPORTANT*

Using RNPs of metal oxides for room-temperature decontamination of chemical and biological warfare agents has shown great promise. RNPs are dry, light powders that react directly with warfare agents by a destructive adsorption process whereby the agent is immediately *detoxified* and *adsorbed* to yield a solid, nontoxic powdery residue. Nanoscale Materials, Inc. currently has cooperative research agreements for the development of commercial air filters, acid gas scrubbing in the petroleum/natural gas industry, and water filtration using reactive nanoparticles. Anticipated DoD uses include rapid dry-powder decontamination of open spaces and surfaces, skin cream to protect soldiers from chemical weapons, protective clothing, air purification, and water purification.



Nantek FAST-ACT  
Decontamination System



*Top: Powdered sorbent being sprayed from a device similar to the M-11 sprayer*  
*Above: Noncorrosive nanoparticle sorbent sprayer similar to the M-11 sprayer, which sprays corrosive decontaminating solution*  
*Left: A quarter ounce of nanoparticles has the surface area of a football field*

## CHEMISTRY: NAVY (ONR)

### POLYMER LIGHT-EMITTING DIODES

#### SUMMARY

The ONR Polymer Programs' focus on conducting polymers helped nurture a field dedicated to a new class of materials, "synthetic metals." While pursuing these new materials, it was discovered that conjugated polymers could have conductivity varying from insulating to semiconducting to conducting, and that the many novel properties of classic semiconductors also occur in these polymers. Developments in the field have reached a point where within a decade organic/polymer or "soft" electronics will have a major impact on society. This was recognized in the 2000 Nobel Prize Awards.

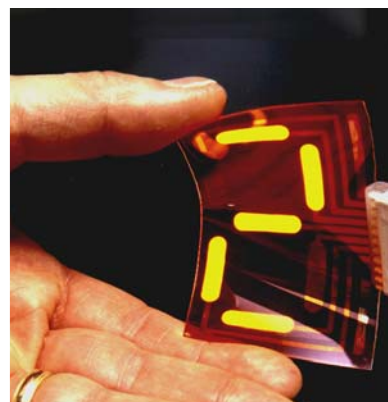
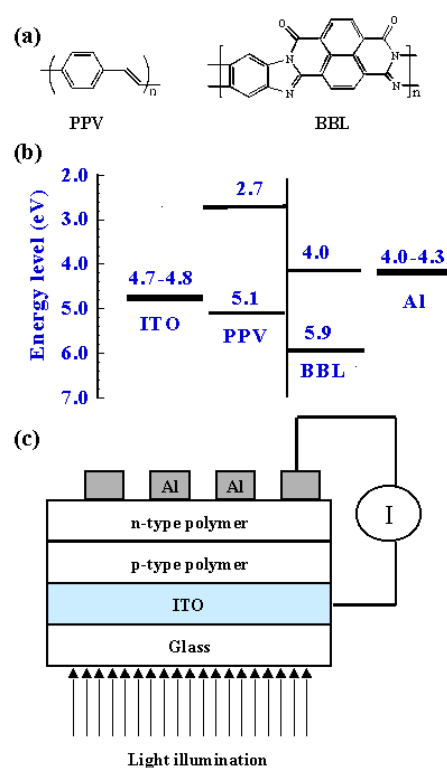
#### WHAT WAS ACCOMPLISHED

The field of organic or "soft" electronics has been pushed forward by basic research supported by DoD in the areas of electroluminescence, photoluminescence, charge transport, and charge injection. In the 1990s, significant investment was made in the pursuit of better performing organic and polymeric light-emitting diodes (LEDs). Navy research focused on synthesis of polymers, doping, processing, and device design. Ultimately this research will impact the Navy, and DoD in general, in areas such as:

- Large-area flat panel displays for ship instrument panels
- Rugged, low-cost, low-power-consuming displays for electronic repair manuals or field deployment
- Thin-film lighting to replace phosphorescent lighting in ships
- Active camouflage
- Novel IR emitters and detectors.

#### WHY IT IS IMPORTANT

Polymeric and organic materials can have the electrical properties of insulators, semiconductors, and conductors. The ability to tailor electronic properties, coupled with the availability of polymers, will allow the development of flexible electronic materials at a fraction of the cost of single-crystal integrated circuits or LEDs. Such work will affect areas such as low-observable coatings; low-cost, field-deployable electronics and displays; sensor and eye protection; inertial navigation; and communications. Due in large part to the initial investment by the Navy, polymer-based electronics are now becoming a commercial reality. Dupont recently purchased UNIAX, a small business founded by ONR-supported researchers and responsible for polymer LED development. The future looks bright for polymer displays, thanks to DoD investment.



## *CHEMISTRY: NAVY (ONR)*

### *THERMOELECTRIC SCIENCE AND TECHNOLOGY*

#### *SUMMARY*

ONR revived its research of thermoelectric (TE) materials to better understand the fundamental science that was limiting the conversion efficiency of these promising materials. As a result, new insights have led to developments, and now these materials are serious contenders for improved shipboard cooling and heating systems.

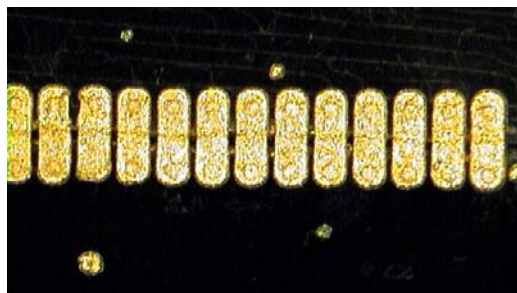
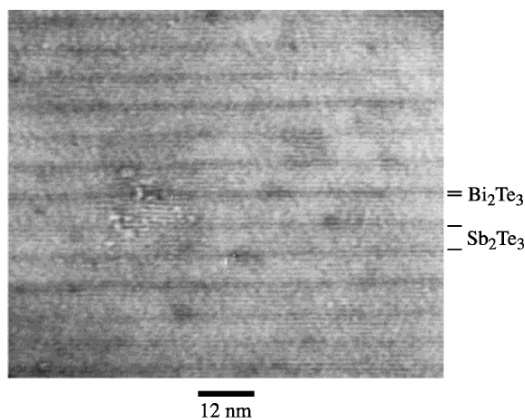


#### *WHAT WAS ACCOMPLISHED*

ONR began funding research in TE materials in 1993 as part of a program to look for alternatives to freon-based cooling systems aboard ships. Thermoelectrics had been investigated by the Navy in the 1960s, and experimental TE cooling modules had been put aboard the USS *Dolphin* in the 1970s. However, the materials lacked the efficiency needed to meet the cooling demands for widespread use in ship compartment cooling. In addition to the cooling applications, these TE materials could ultimately be used to convert heat sources aboard naval platforms into electrical energy. In the 1990s, ONR set out to discover and understand the science that would lead to new TE materials with potentially higher efficiency. Basic research efforts in solid-state chemistry and engineering nanostructures of thermoelectric materials into macroscopic materials were pursued. Through basic research support, a major advance was made in a field that has stagnated for over 30 years. The program has discovered countless new compositions of matter with greatly improved properties. The success in the basic research has led to a revival of interest in thermoelectrics for cooling electronics and for power scavenging.

#### *WHY IT IS IMPORTANT*

Industry is beginning to address manufacturing issues associated with the new materials that have been developed. Technology programs to incorporate efficient thermoelectrics based on new materials are underway through collaborative programs with DARPA. The advances made in TE science have led the DoD community to take a serious look at these materials for power generation in distributed wireless sensors and for shipboard cooling/heating.



*Top: Boules made by industry collaborator*  
*Above: Thermoelectric devices based on the new superlattice structure*  
*Left: Thermoelectric superlattice*

## *CHEMISTRY: AIR FORCE (AFOSR)*

### *DEVELOPMENT OF ELECTRO-OPTICAL POLYMERS*

#### *SUMMARY*

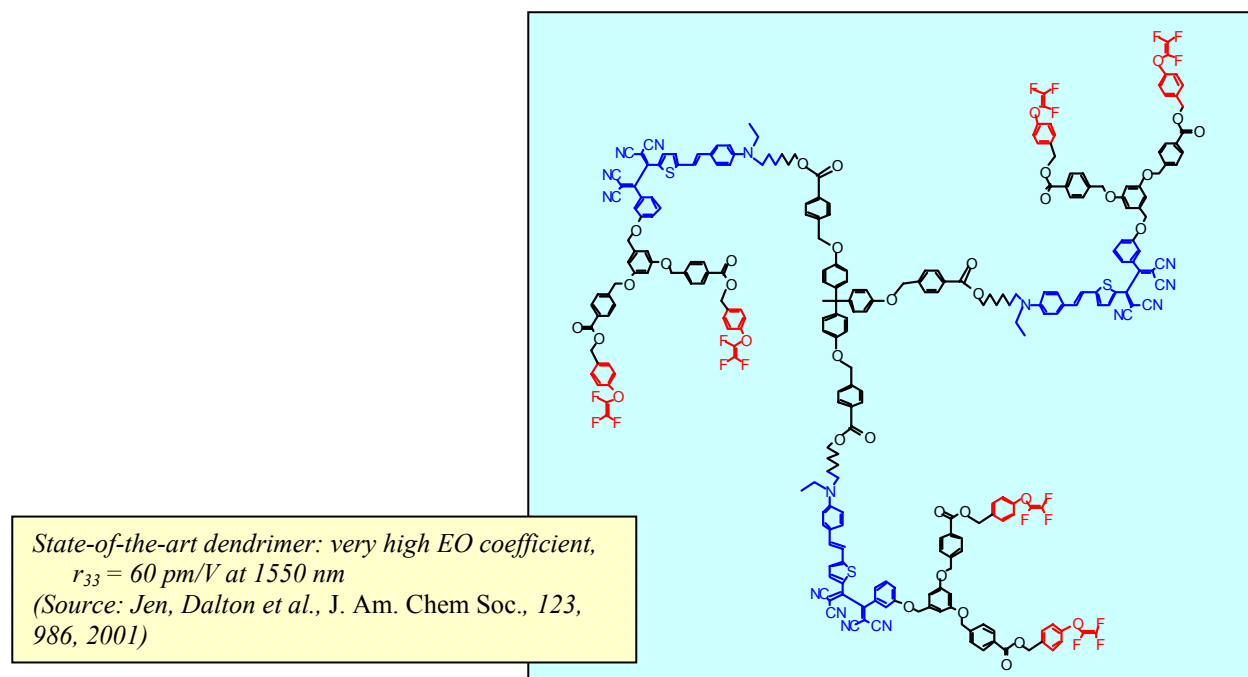
Basic research in this area has made possible the manufacture of electro-active polymers with much greater purity. As a result, applications that were not possible a decade ago are becoming feasible today.

#### *WHAT WAS ACCOMPLISHED*

Since the first generation of electro-optical polymers was studied more than 12 years ago, the research effort has had to overcome many material and processing issues discovered during the device research phase. Problems that were overcome include poling stability, optical stability, electro-poling efficiency, translation of molecular properties into large electro-optical coefficient materials, and optical loss and sensitivity at communication wavelengths. After several generations of materials research and collaborative efforts, electro-optical polymers are now being studied for various applications that include telecommunications, phased-array radar control, global surveillance, and optical gyros.

#### *WHY IT IS IMPORTANT*

The latest state-of-the-art material is a dendrimer molecule, shown in the figure below. The applications for devices for this class of polymers are currently being explored by commercial companies such as Pacific Wave, Lumera, Lucent, and IBM; by aerospace companies such as Lockheed Martin and Boeing; and by military organizations such as the Naval Air Warfare Center (NAWC) in China Lake, the Air Force Sensor Directorate, and the Naval Reconnaissance Office.



## *COGNITIVE AND NEURAL SCIENCES: AIR FORCE TEAM TRAINING AND PERFORMANCE*

### *SUMMARY*

Air Force-sponsored researchers have been studying how to optimize the training and performance of teams. One important approach has been to develop laboratory simulations of prototypical operational environments such as the Airborne Warning and Control System (AWACS) and unmanned aerial vehicle (UAV) tasks, and to make these test environments available to university scientists.

### *WHAT WAS ACCOMPLISHED*

Computational models of the perceptual, motor, and cognitive processes involved in basic UAV control and reconnaissance tasks were developed and used to predict operator behavior and the effects of operator characteristics on performance. Other studies examined the effects on team performance of geographically distributing vs. co-locating team members. Distribution had a small effect on performance but a large effect on team member workload. Team composition and differences in the working memory abilities among the team members also affected performance.

### *WHY IT IS IMPORTANT*

Simulated task environments (STEs) are designed to reproduce the essential features of the operational task within a controlled and reproducible laboratory environment. STEs provide scientists with a common test platform for performing experiments on team communication, training, and dynamic decisionmaking, and enable researchers to compare and generalize their findings to real-world settings. Using these platforms, academic researchers have begun to develop computer models of expert operator behavior and to evaluate the use of artificial machine agents as decision aids and teaching proctors. An important research goal is to optimize the design of person-system interfaces and of networked communication systems. By specifying and manipulating the cognitive mechanisms that distinguish novice from expert operators, it should be possible to greatly decrease the time and cost of operator training in these complex environments.



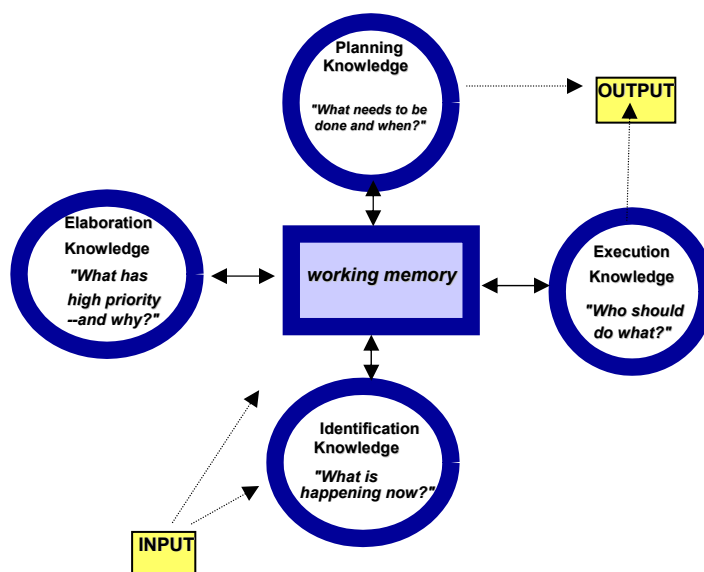
*Views of control console and sample team member displays in UAV environments (Pictures courtesy of Dr. Nancy Cooke, NM State University, and Dr. Kevin Gluck, AFRL-Mesa)*

## *COGNITIVE AND NEURAL SCIENCES: NAVY*

### *SCHEMA THEORY/EYE TRACKING METHODOLOGY FOR DESIGN AND EVALUATION OF COMPLEX DISPLAYS*

#### *SUMMARY*

Dr. Sandra Marshall at San Diego State University and Dr. Jeffrey Morrison at the Space and Naval Warfare System Center (SPAWARSYSCEN) have been collaborating to explore the application of schema theory-based models of tactical decision-making and eye-tracking technology as tools for design and evaluation of human-system interfaces (HSI) in support of air contact processing by commanding officers and tactical action officers in combat operation centers



#### *WHAT WAS ACCOMPLISHED*

Schema theory developed at San Diego State University was shown to be a workable model for sorting command decision processes into four components: identification, elaboration, planning, and execution. A parallel effort at SPAWARSYSCEN developed a decision support system and HSI based on decision theory that mapped onto the components. Eye-tracking technology was used to describe scan patterns as a means to evaluate the display field design and to distinguish experienced officers from inexperienced officers.

#### *WHY IT IS IMPORTANT*

The combination of schema theory-based models of tactical decisionmaking and eye-tracking technology provides powerful tools for the design and evaluation of complex displays. Historically, display design has been mainly creative engineering.



## *COGNITIVE AND NEURAL SCIENCES: ARMY (ARO I)*

### *TRAINING CULTURAL DECENTERING*

#### *SUMMARY*

The U.S. Army Research Institute for the Behavioral and Social Sciences (ARI) sponsored an investigation into the differences in behavior and customs across cultures. In addition to helping to understand these differences, the research is also focused on developing training that can help Army personnel to handle working within multicultural forces better.

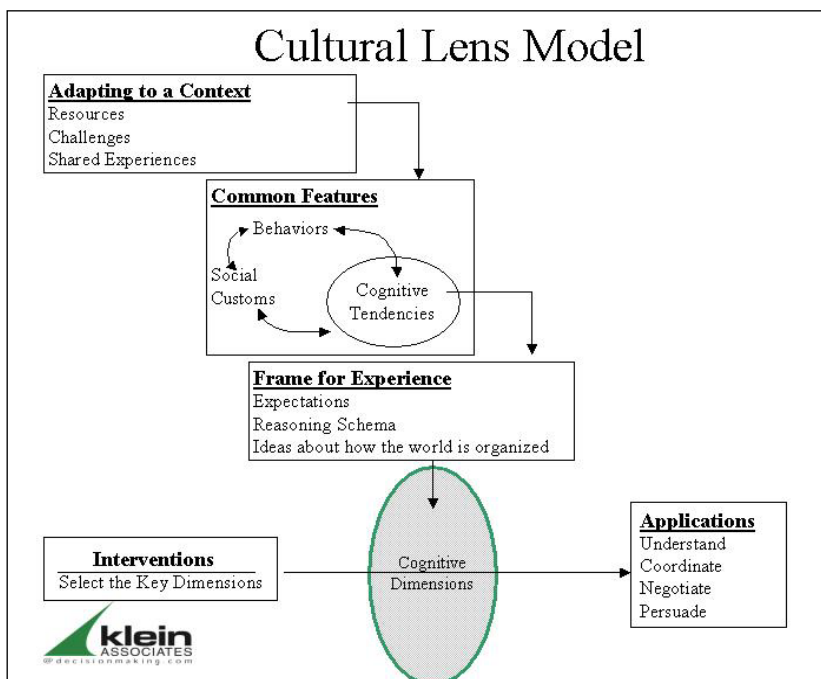
#### *WHAT WAS ACCOMPLISHED*

A culture-based model of the cognitive dimensions that differentiate individuals from different cultures, the “Cultural Lens Model,” was developed and elaborated. Among the dimensions that were investigated were *tolerance for uncertainty* and *analytic-holistic reasoning*. Based on the Cultural Lens Model, training was designed to increase the awareness, acceptance, and prediction of the behavior of those from different cultures. Researchers used a decentering intervention, intended to expose subjects to cultural perspectives and approaches different from their own. After training, subjects showed significant increases in both awareness and acceptance.

#### *WHY IT IS IMPORTANT*

The findings of this research suggested that decentering training, using the Cultural Lens Model, improved the ability of personnel to recognize and deal with cultural differences. Using this approach, additional training interventions are being developed.

The results of this research are being used by ARL to develop Web-based training models in cultural forms of cognition for officers serving on multinational teams in Bosnia. Since the Army is likely to be involved in a greater number of multinational forces and missions, the ability to avoid culturally based disagreements becomes increasingly important. Understanding how individuals from different cultures construct and solve problems is a key step for avoiding problems before they occur or minimizing their impact once they do.



## *COGNITIVE AND NEURAL SCIENCES: ARMY (ARO 2)*

### *RECOGNITIONAL DECISIONMAKING*

#### *SUMMARY*

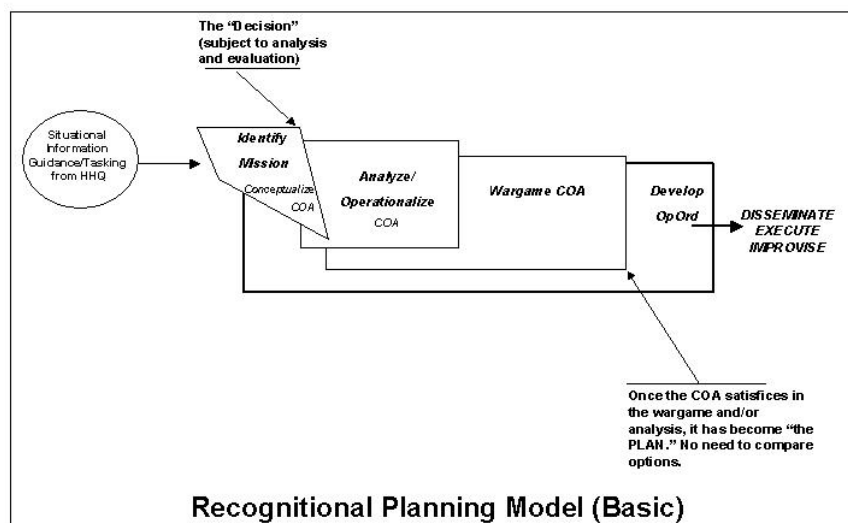
The U.S. Army Research Institute is sponsoring a series of studies investigating models of recognitional decisionmaking (RDM). This research includes model development, assessment, and training of decisionmaking approaches and their application to minimizing the time and effort necessary to generate operations orders.

#### *WHAT WAS ACCOMPLISHED*

Through a series of 3-year projects, this research has developed and elaborated an RDM model. Based on natural decisionmaking models, RDM helps individuals to generate reasonable courses of action without the requirement to compare options, thereby speeding up the decisionmaking process. Early research efforts developed RDM models and identified the components and linkages that describe how individuals use RDM. Later efforts focused on training, improving, and implementing RDM among key decisionmakers in a variety of laboratory and field settings. The research on RDM funded by ARI was documented in the book, *Sources of Power: How People Make Decisions* (Klein, 1988, MIT Press). A second book, *Intuition at Work* (Klein, New York: Doubleday Currency, in press), will describe methods for improving intuitive decisionmaking skills.

#### *WHY IT IS IMPORTANT*

The ability of commanders at all levels to make more timely and efficient decisions, especially under the time and situation pressures, is of critical importance to the success of modern Army missions. The results of this research effort are currently being applied by the Battle Command Battle Laboratory at Ft. Leavenworth (BCBL-L). The Objective Force Task Force has charged BCBL-L to find an alternative to the currently used military decisionmaking process. BCBL-L researchers are testing the recognition-primed model (RPM) that evolved from this research on naturalistic decisionmaking. The RPM is designed to dramatically reduce the time and effort needed to generate operations orders under the military decisionmaking process. The pace of battle will be accelerated for the Objective Force. The BCBL-L is also testing the RPM model as the means for minimizing the time and effort necessary for decisionmaking in a variety of Army missions.



## *COGNITIVE AND NEURAL SCIENCES: ARMY (ARO 3)*

### *ARMY LEADERSHIP DEVELOPMENT: PRACTICAL KNOWLEDGE ASSESSMENT*

#### *SUMMARY*

Scientists at the PACE Center at Yale University and Knowledge Analysis Technologies, LLC are investigating how the theory of tacit knowledge structures can be applied to accelerate military leadership development. The Tacit Knowledge for Military Leadership (TKML) battery was developed to assess practical knowledge skills gained through career experiences. Currently, the TKML is being extended as a training tool used in an on-line collaborative classroom environment to accelerate the acquisition of military leadership.

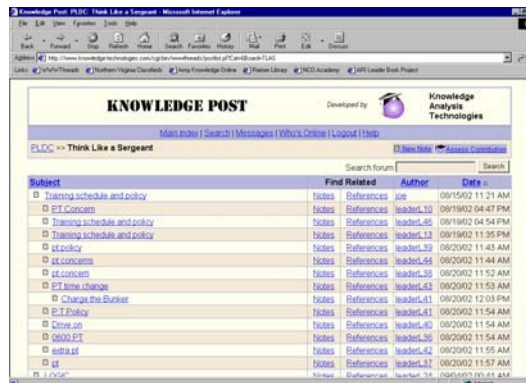
#### *WHAT WAS ACCOMPLISHED*

To understand how the practical, experiential knowledge gained by military leaders during the course of their careers might be developed rapidly in more junior leaders, the concept of learning through tacit knowledge structures, developed by Dr. Robert Sternberg and others at the PACE Center, was applied to military leadership. Career officers were interviewed about experiences that had enabled them to learn about effective leadership, and common themes were extracted and compiled into the TKML assessment battery.

Initial research results showed that TKML scores predicted leadership effectiveness better than rank, experience, and other traditional assessments, such as verbal ability. The next step was to transform the TKML into a format that could be used to develop this knowledge in a training environment. Knowledge Post, an online collaborative setting that allows users to type in responses to TKML scenarios, was the result. Soldiers give feedback on each other's responses as well as search for other similar responses to guide discussion by using latent semantic analysis, a new technology in which a computer analyzes free-text entries to compare similarity of responses. This technology also gives soldiers immediate feedback from experienced military personnel during the training sessions. This helps them to ascertain how their responses compare with those of others.

#### *WHY IT IS IMPORTANT*

The Army is interested in developing effective officer and enlisted leaders to quickly prepare junior soldiers for critical decisionmaking in a wide range of assignments and situations. Since soldiers cannot train in all the possible situations where decisions must be made, tools to develop these thinking skills are critical to the success of the Army of tomorrow. Building practical knowledge through Knowledge Post allows soldiers to learn from the experiences of others and to develop decisionmaking skills that normally would take years to acquire through actual hands-on experience. This application of tacit knowledge theory-based research is helping the Army to more rapidly develop knowledgeable military leaders.



## COGNITIVE AND NEURAL SCIENCES: ARMY (ARL 4)

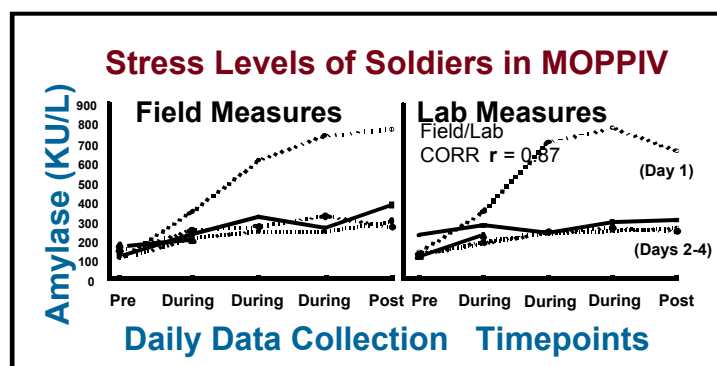
### FIELD EXPEDIENT STRESS MEASUREMENT

#### SUMMARY

Researchers at the Army Research Laboratory, in collaboration with scientists from Northwestern University Medical School, have developed a field-practical assay of salivary amylase as a noninvasive, physiological measure of stress. The amylase levels provide a rapid, reliable, and quantifiable measure of stress intensity. When combined with a self-report measure, the new stress measurements provide critical diagnostic information for specific stress components that influence warfighter performance.

#### WHAT WAS ACCOMPLISHED

A multidimensional approach was used to assess the responses of soldiers in stressful situations, such as conditions of extreme thermal stress and intense training. Data from psychological trait and state questionnaires were collected in conjunction with blood samples for assaying hormones and saliva for on-site assays of amylase. Based on a series of laboratory and field studies, salivary amylase was found to be a valid and reliable measure of adrenergic activity during conditions of physical and psychological stress in humans. The resulting Salivary Amylase Field Test Kit provides a way to measure warfighter stress levels in virtually any environment. The field test kit is used with selected self-report measures that have proven sensitive to the degree of stress experienced in a variety of situations and have demonstrated construct validity within the stress research literature. This field-expedient method of stress measurement provides critical diagnostic information that identifies specific components of stress that influence warfighter performance.



#### WHY IT IS IMPORTANT

The identification of soldier stress response profiles in uncertain and hostile environments assists the selection of appropriate countermeasures. Decisions to implement stress countermeasures in any domain must consider interactions among the human, environmental, and organizational factors associated with mission success. Stress response profiles obtained from field stress measures can also be used to enhance the cognitive readiness of military forces by (1) providing rapid, reliable assessments of technology integration, including measures of effectiveness of simulations and mission rehearsals; (2) identifying stress-resilient characteristics of individuals, teams, and organizations; (3) serving as a warning of chronic stress levels that may have deleterious effects on health and performance; (4) serving as a decision aid for leaders and medical personnel to determine redirection if needed; and (5) serving as a predictor of adaptability, training performance, and susceptibility to motion and sea sickness.

*Top: Using a field-practical kit, technician quantifies stress levels in 5 min or less.  
Right: Field assays of salivary amylase correlate significantly with lab results.*



*ELECTRONICS: NAVY (ONR)**MULTIFUNCTIONAL MATERIALS: SUPERCONDUCTING DIGITAL LOGIC**SUMMARY*

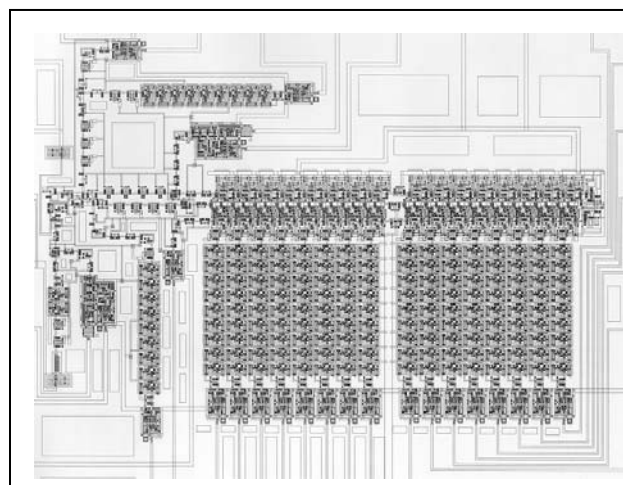
Physicists and materials researchers at Penn State, MIT, and Arizona State have succeeded in growing films of superconducting  $\text{MgB}_2$ . This new material could increase the maximum speed of superconductive digital logic by a factor of three and operating temperature by a factor of five, thus improving energy efficiency and ease of packaging.

*WHAT WAS ACCOMPLISHED*

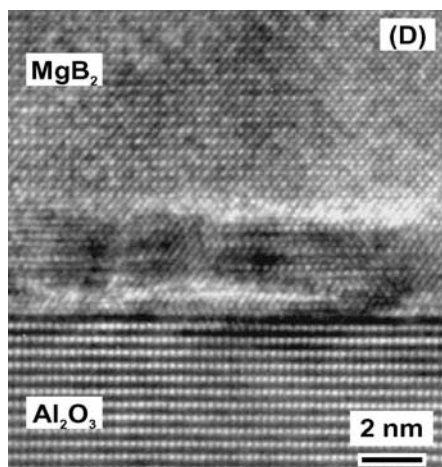
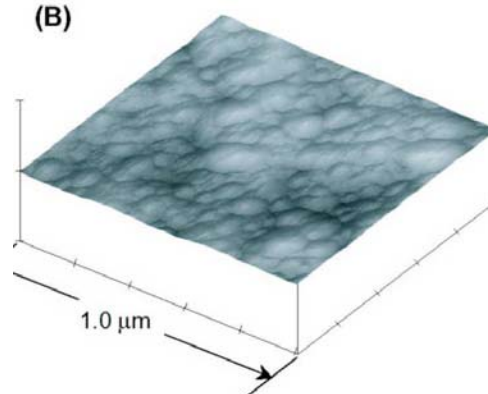
High-quality  $\text{MgB}_2$  films have been grown by an in situ deposition method on SiC and  $\text{Al}_2\text{O}_3$  substrates. The films are very smooth with 2.5-nm surface roughness. No post-deposition anneal is required to achieve the full superconducting transition temperature of 39 K. Critical current densities are greater than  $107 \text{ A/cm}^2$ .

*WHY IT IS IMPORTANT*

$\text{MgB}_2$  is a newly discovered superconductor whose properties fall between those of the metallic low-temperature superconductors (e.g., Nb) with isotropic properties and long coherence lengths, but low (4 K) operating temperatures, and those of the oxide high-temperature superconductors discovered in 1997. The latter could operate much warmer but have much more difficult fabrication requirements and problematic anisotropy and parasitic properties.  $\text{MgB}_2$  digital devices and circuits will operate at liquid hydrogen temperatures at 20 K to deliver about twice the energy efficiency of any other digital technology. The logic speed should also be high enough to make direct RF reception a reality.



(B)



Top: Superconducting digital correlator  
Above: Surface image  
Left: Cross-sectional TEM image

*ELECTRONICS: NAVY (ONR)**NANOSCIENCE: INP DEVICES FOR DIRECT DIGITAL SYSTEMS**SUMMARY*

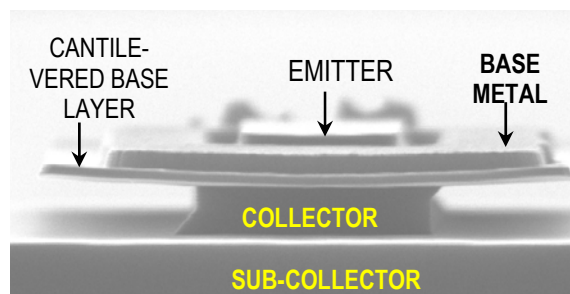
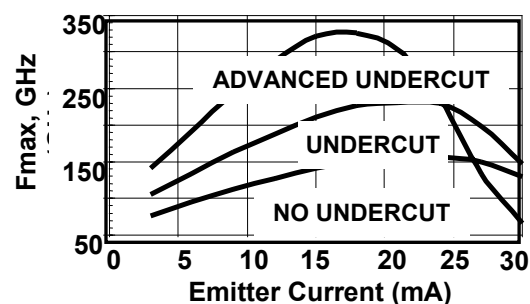
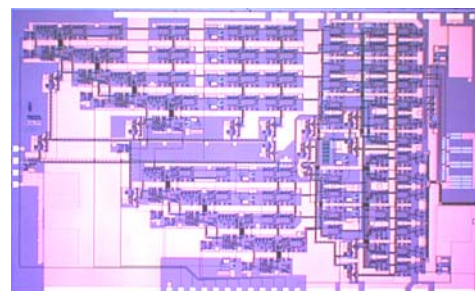
Scientists at the University of California at Santa Barbara have pioneered innovative device structures that dramatically increase the speed of digital circuits aimed at direct digital synthesis (DDS) of high-frequency radar signals. Devices fabricated by this advanced process have been incorporated into DDS circuits by TRW.

*WHAT WAS ACCOMPLISHED*

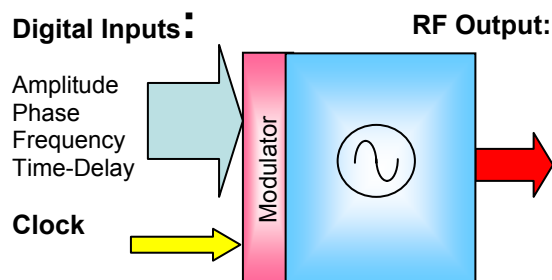
An indium phosphide (InP)-based double heterojunction bipolar transistor with a cantilevered base suspended above the undercut collector has an  $f_{max}$  more than two times higher ( $>300$  GHz) than its conventional counterpart. The increase in speed comes from a reduction of the device capacitance. This extremely high device frequency of operation must be achieved to obtain DDS performance at microwave and radar frequencies.

*WHY IT IS IMPORTANT*

Multifunction RF systems depend on digital synthesis to allow simultaneous operation at different frequencies. This technology has allowed the fabrication of the highest complexity InP circuit to date, with fully functional chip yield of  $\sim 50$  percent. TRW has used this to produce the first multi-GHz DDS with 8-bits of frequency control, 7 bits of magnitude, and  $-130$  dBc phase noise at 100-Hz offset. Advances in ultra-high-speed logic are providing new digital capabilities to generate arbitrarily complex RF waveforms that will revolutionize future radar, communications, and electronic warfare systems.



Above: Scanning electron microscope image of fabricated cantilevered-base HBT



Top: Chip photo, +3000 HBT DDS  
Middle: Measured  $F_{max}$   
Above: DDS functionality

*ELECTRONICS: ARMY (ARO) AND OSD**BIOENGINEERING SCIENCES: REMOTE BIOLOGICAL AGENT DETECTION**SUMMARY*

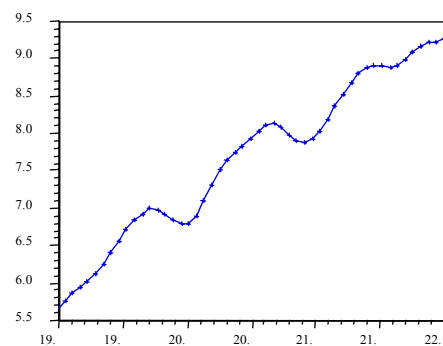
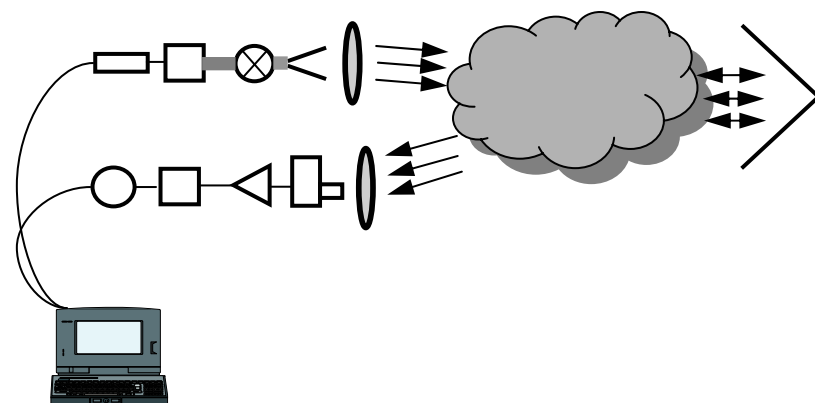
Scientists and engineers at the University of Virginia, UCLA, the University of Michigan, Stevens Institute, and the University of Tennessee are developing technology and measurement techniques to support the use of the terahertz frequency spectrum for remote detection of biological agents. Aerosol detection ranges of about a kilometer should be possible through use of this technology.

*WHAT WAS ACCOMPLISHED*

Pioneering research has demonstrated that bioparticles, such as bacillus subtilis spores (a simulant for anthrax), possess strong spectroscopic absorption peaks within the terahertz (0.3–2 THz) region of the electromagnetic spectrum. Some of these resonant peaks are strong enough to be remotely detected by a coherent differential-absorption radar (DAR) with a retroreflector. Such a system should be able to readily detect projected bioparticle clouds at a range of 1 km by using a modest transmitter power of 1 mW.

*WHY IT IS IMPORTANT*

The system sensitivity studies that were performed accurately included the effects of atmospheric attenuation, used readily available high-frequency components, and derived probability-of-detection (PD) and probability-of-false-alarm (PFA) statistics for bioparticle clouds of realistic size and density. Such an investigation has a high relevance to civilian and military defense because it has the potential to define a feasible and effective technique for early warning of a biological agent attack. The development of terahertz sources and detectors will also find uses in free-space transmission of real-time video information, as well as high-frequency electronics.



*Above: Laboratory measurements of absorption on BG spores at ~0.6 THz  
Left: DAR with retroreflector*

## *ELECTRONICS: ARMY (ARO) AND DARPA*

### *NANOSCIENCE: RESONANT TUNABLE DETECTION OF TERAHERTZ RADIATION*

#### *SUMMARY*

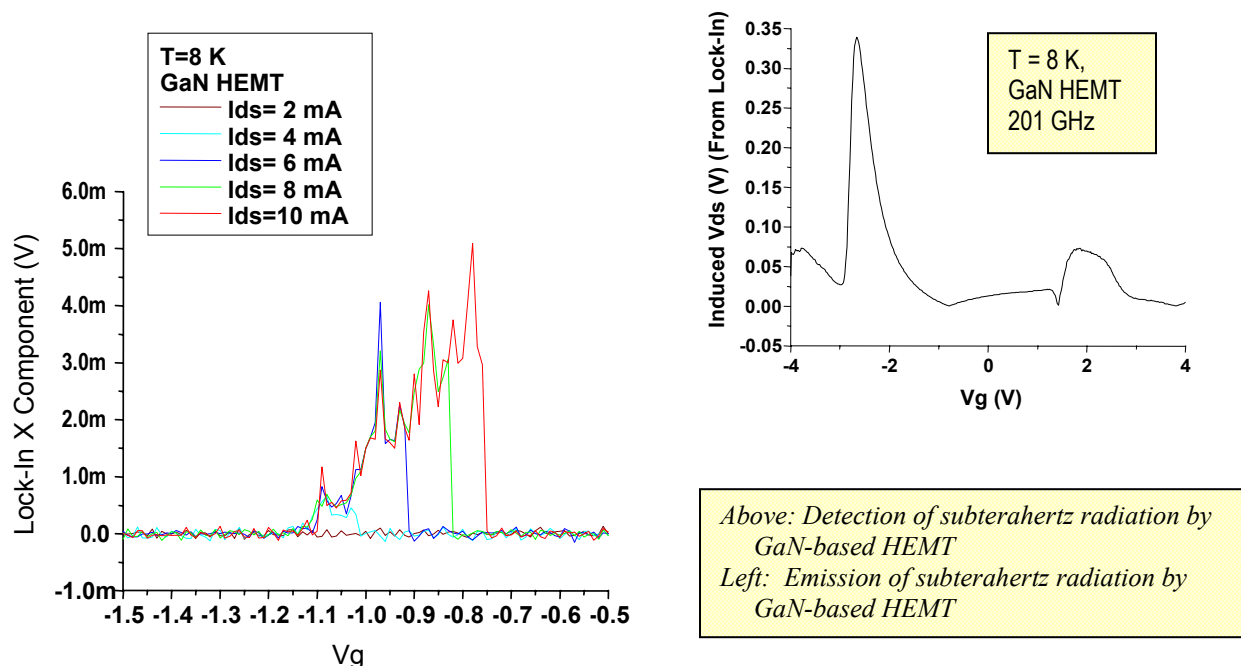
Scientists and engineers at Rensselaer Polytechnic Institute are developing technology for resonant tunable detection and emission of terahertz radiation using deep-submicron field-effect transistors. This technology is expected to lead to the development of portable terahertz systems for multiple DoD and commercial uses.

#### *WHAT WAS ACCOMPLISHED*

This pioneering research has demonstrated resonant detection of terahertz radiation by gallium arsenide (GaAs)-based and gallium nitride (GaN)-based high-electron-mobility transistors (HEMTs) at 200 GHz, 600 GHz, 800 GHz, and 1.2 THz. Strong, nonresonant detection was also demonstrated at room temperature. For the first time, the terahertz emission by HEMTs was observed. A new theory of plasma wave detection showed that tunneling and barrier-injection transit-time mechanisms of terahertz plasma instability in two-dimensional heterostructures should enhance the terahertz detectivity. The experimental data revealed that the detection peak at high gate currents was in agreement with this theory.

#### *WHY IT IS IMPORTANT*

The development of reliable terahertz components will impact scores of applications, including the detection of hazardous biological agents, antiterrorist countermeasures, industrial and environmental controls, medicine (for cancer detection and treatment), short-range communications for wireless “last mile” Internet solutions, and space communications. This project has demonstrated, for the first time, that such detectors and sources can be realized using standard semiconductor technology that should allow the “terahertz gap” in the electromagnetic spectrum to be closed.

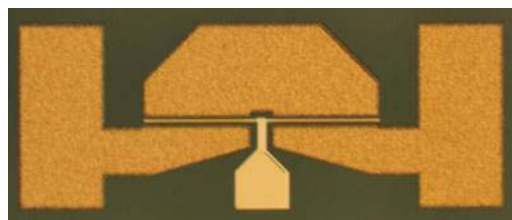


*ELECTRONICS: NAVY (NRL)**NANOSCIENCE: CHARGE TRAPPING IN GAN FIELD-EFFECT TRANSISTORS**SUMMARY*

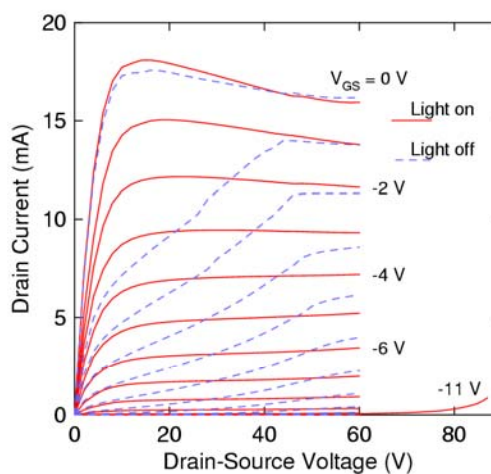
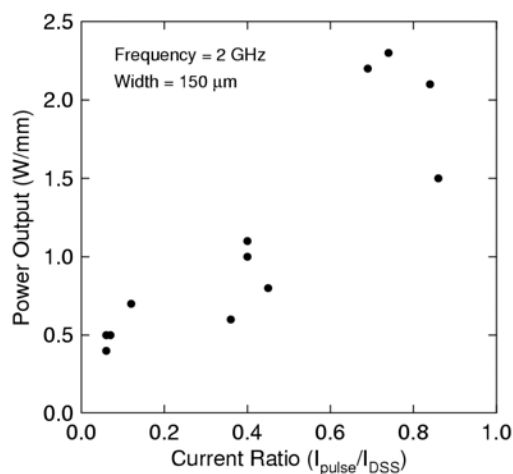
Scientists at NRL have identified trapping effects associated with the surface and with the layers underlying the active channel in GaN-based field-effect transistors (FETs). Traps can be used to explain an industry-wide observation of “current collapse” in these devices. Eliminating the sources of these trapping effects has been shown to result in improved microwave performance in NRL devices.

*WHAT WAS ACCOMPLISHED*

Measurement techniques were established to identify these trapping effects. Device and materials modifications, such as modified buffer layer growth and surface passivation, were developed to minimize these deleterious effects. Reduction in trap density has resulted in greater microwave power performance.

*WHY IT IS IMPORTANT*

Trapping effects can limit the output power performance of microwave FETs. Next-generation radar systems require the higher performance available from the wide-bandgap materials. Elimination of trapping effects is critical to establishing a high-performance, reliable, wide-bandgap technology base needed for future military systems.



Top: NRL GaN HEMT, top view

Above left: Correlation of microwave power output with pulse drain current measurements

Above right: Collapse observed in GaN metal semiconductor field-effect transistors

*ELECTRONICS: NAVY (NRL)**NANOSCIENCE: HIGH-SPEED 6.1-ANGSTROM DEVICES**SUMMARY*

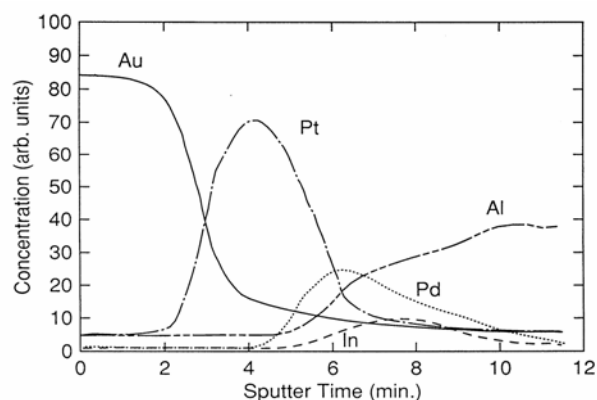
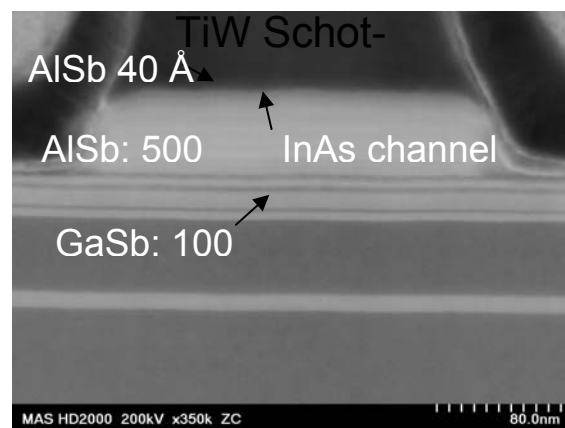
Scientists at NRL and TRW have collaborated to pioneer innovative material growth and device structures in the 6.1-angstrom (AlSb/GaSb/InAs) material system that enable high-speed operation with dramatically decreased power dissipation.

*WHAT WAS ACCOMPLISHED*

AlSb/InAs high-electron-mobility transistors with advanced material growth designs and Pd/Pt/Au ohmic and TiW/Au gate metalizations were used to increase speed, minimize contact diffusion, and improve thermal stability. The new material exhibits record electron mobility and sheet density. The devices exhibit a tenfold reduction in gate leakage current, a record-high transconductance of 1.4 S/mm at 0.55-V drain voltage, and substantially improved thermal stability. The low-voltage device has a power dissipation 10 times lower than its conventional counterpart.

*WHY IT IS IMPORTANT*

Future high-speed receiver applications that require lightweight power supplies, long battery lifetimes, and improved efficiency will require transistors that consume less power. Military and commercial applications include space-based communications, imaging, sensing, micro air vehicles, wireless applications, and other portable systems. The extremely high frequency capability and low consumed power of these devices makes them the leading candidate technology for the next generation of high-speed, low-power electronics. Successful transition of existing NRL technology to TRW was accomplished.



Top: HEMT STEM Image (350,000x),  
 $m = 20,400 \text{ cm}^2/\text{V-sec}$ ,  $n_s = 3.3 \times 10^{12} \text{ cm}^{-2}$   
 Above: Auger spectra of shallow, low-resistance  
 Pd/Pt/Au ohmic contact after alloying

*MATERIALS: ARMY**POLYMER COMPOSITES RESEARCH**SUMMARY*

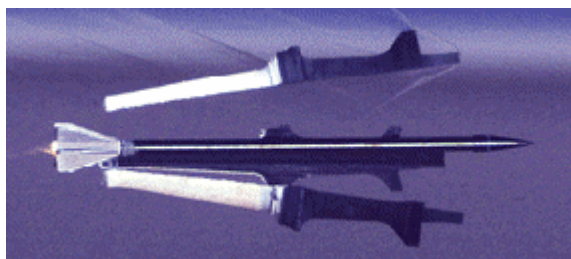
Over the past two decades, Army-funded research on polymer composites design and manufacture has advanced the technology to the point where it is now being introduced into Army combat vehicles and systems. The benefits for the Army are smaller, lighter weight combat systems with improved transportability and battlefield survivability. The largest sustained academic program in this area is the Center for Composite Materials at the University of Delaware.

*WHAT WAS ACCOMPLISHED*

Supported by the Army since 1985, the center has been conducting a broad research program in composites manufacturing that directly addresses the historically high processing and assembly costs associated with the manufacture of composite structures. Major advances in automated composite section processing, component joining, and ballistic and structural performance have been achieved. In advancing the technology, the Center for Composite Materials has established strong ties to the composites industry and to the Army science and technology community. The center has established collaborative efforts with over 100 industries since its start, and in 1999 was cited by the National Research Council as a model for university–government collaboration.

*WHY IT IS IMPORTANT*

Research at the Center for Composite Materials has begun to transition to the field. Basic research on induction processing was transitioned to Alliant for development of a lightweight composite sabot for the M-829E3 munition (shown below), which is now a fielded system. University of Delaware research on diffusion-enhanced adhesion and co-injection resin transfer molding of composites was used in the U.S.



Army Tank–Automotive Research, Development, and Engineering Center composite armored vehicle (CAV) advance technology demonstration (ATD) project in the mid-1990s, and has been transitioned to United Defense L.P. for application in the Crusader Self-Propelled Howitzer. And this is only the beginning. The application of composites on future combat vehicles and weapon systems seems certain as the Army seeks to develop a lighter, more deployable combat force.

## *MATERIALS: AIR FORCE (AFOSR)*

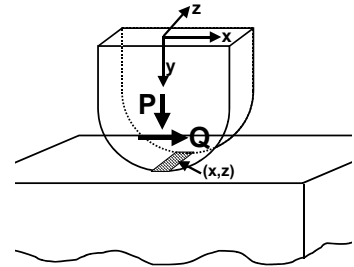
### *COMPUTATIONAL MODELS AID DESIGN OF FATIGUE-RESISTANT GAS TURBINE ENGINES*

#### *SUMMARY*

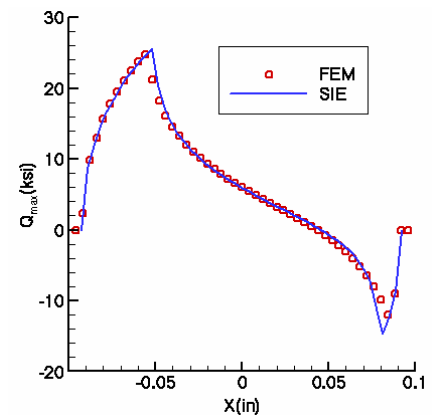
Research sponsored under AFOSR's National High-Cycle Fatigue (HCF) Initiative at the Materials and Manufacturing Directorate, AFRL, and the School of Aeronautics and Astronautics, Purdue University, in collaboration with industry at General Electric Aircraft Engines (GEAE), has resulted in improvements in the prediction of contact stresses that are the source of fatigue crack initiation in the blade/disk attachment region of turbine engines.

#### *WHAT WAS ACCOMPLISHED*

All engine manufacturers have adopted finite element methods (FEMs) as an industry standard for the design of turbine engine components. When two components come into contact, such as the region where turbine blades are attached to the disk, the mutual forces exerted cause stress fields in each that rise to very high values over small distances. In the upper figure, the shaded area represents the contact region and  $P$  and  $Q$  are normal and tangential forces exerted by the upper component (blade) on the lower component (disk). Stress analysis of the contact region requires the use of many extremely small computational elements to calculate the stress accurately. The cost and computational time required for this refinement makes FEMs impractical for design in the vicinity of such contacts. Lack of accurate stress calculations renders the design of the blade-disk contact region less reliable than that for other parts of the engine, which lowers the reliability and increases the risk of failure due to the initiation of a potentially catastrophic fatigue crack.



To calculate stresses in this region, a quasi-analytical solution has been developed for two-dimensional contact problems using singular integral equations (SIEs). The SIE method has been exercised at GEAE and found to be very robust and easy to use. The code was used to generate stress results for fretting tests conducted under the HCF initiative. The SIE results were then compared with previously calculated finite element results, as illustrated in the lower figure. Predicted peak stresses for SIE methods were found to be within 5 percent of the most accurate finite element results. However, the SIE solution took minutes to achieve, while the finite element results were obtained only after weeks of computational solution time. Based on the results of the comparison, a hybrid combination of "coarse" three-dimensional finite element methods with two-dimensional integral equation methods was suggested as an accurate and cost-effective method for three-dimensional analyses.



#### *WHY IT IS IMPORTANT*

The most important contribution of the SIE methods is its ability to determine an accurate stress state in the contact region in a reasonable computational time. Accurate calculations of contact stresses are now paving the way for more reliable methods of life determination and allowable stress thresholds. These results will help to reduce the uncertainty in a component's ability to withstand HCF damage. This will allow industry to remove unnecessary conservatism from engine design, thus increasing performance by decreasing engine weight while simultaneously increasing reliability.

## *MATERIALS: NAVY (ONR)*

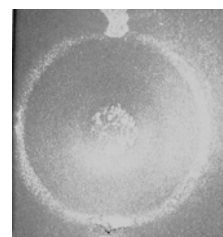
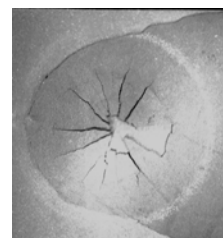
### *NEW CERAMIC COATING*

#### *SUMMARY*

A revolutionary new coating, developed under the ONR S&T program, has been qualified for use on U.S. Navy ships. This new ceramic coating exhibits excellent wear resistance and bond strength, combined with unprecedented toughness. Such a combination of properties has never before been achieved in a ceramic material.

#### *WHAT WAS ACCOMPLISHED*

This new technology enables the use of ceramic coatings (with their inherent advantages of chemical inertness, and elimination of galvanic corrosion and calcareous deposits) in situations where ceramics could never before be used, and often enables the repair rather than the replacement of a worn or damaged component. The new coating actually has the same composition as an existing commercial coating and is produced using the same thermal spray equipment (widely available at Navy facilities and commercial suppliers). What is different is a unique “duplex” microstructure consisting of small regions of micron-sized grains embedded in a very fine “nanoceramic composite” with grain sizes less than 100 nm. This structure is remarkably effective in preventing small “microcracks” from propagating or linking up to cause failure. This is illustrated in the figures to the right, which show the response of a conventional and nanostructured coating to severe deformation of the substrate. The conventional coating (top) exhibits severe cracking that leads to loss of the coating (spalling); the nanostructured coating (bottom) deforms along with the substrate and shows no visible cracking. This ability to deform without failure enables the use of ceramic coatings in applications where ceramics could not be used before.



<i>SHIP COMPONENTS—SOME APPROVED</i>	<i>FOR FLEET USE—OTHERS ALREADY INSTALLED</i>
<i>CVN Lube Oil Pumps, Carbon Packing Seal Area</i>	<i>High &amp; Low Pinion Speed Gear Shaft SSTG Turbo Compressor</i>
<i>Submarine AI/DE Valves</i>	<i>AN/BRA-34 Mast Hoist Hydraulic Cylinder Rod</i>
<i>Main Propulsion Shafts (MCMs)</i>	<i>Inner Mast Lower Bearing Sled Weldment</i>
<i>80-Ton A/C Gear Sets</i>	<i>Socket Bracket Weldment</i>
<i>Feed Pump Turbine Bearing Journals</i>	<i>Submarine Hull Closure Components</i>

#### *WHY IT IS IMPORTANT*

An example of a component taken from an air conditioning unit used on surface ships (in this case, a Nimitz class carrier) illustrates damage sustained by a reduction gear. The component is a single forging. In the past, such damaged components have been discarded and replaced at a cost of \$15,000 per set. The upper image illustrates the same component after repair by machining down below the damaged area, coating with the nanoceramic composite, and grinding to original tolerance. The repair costs approximately \$500. When fully implemented, the Navy will save approximately \$500,000 annually in maintenance costs for this one component. Given the large number of components amenable to repair using this new technology, the potential exists for avoiding tens of millions of dollars per year in maintenance and replacement costs.



*MATHEMATICS AND COMPUTER SCIENCES: ARMY (ARO)*  
*FLASH VAPORIZATION—VISCOUS LIQUID TO VAPOR AND BACK*

*SUMMARY*

Research at the University of Minnesota, through an ARO MURI, has identified flash vaporization—that is, cavitation of superheated liquid under low pressure—and subsequent condensation as the mechanisms that form this mist.

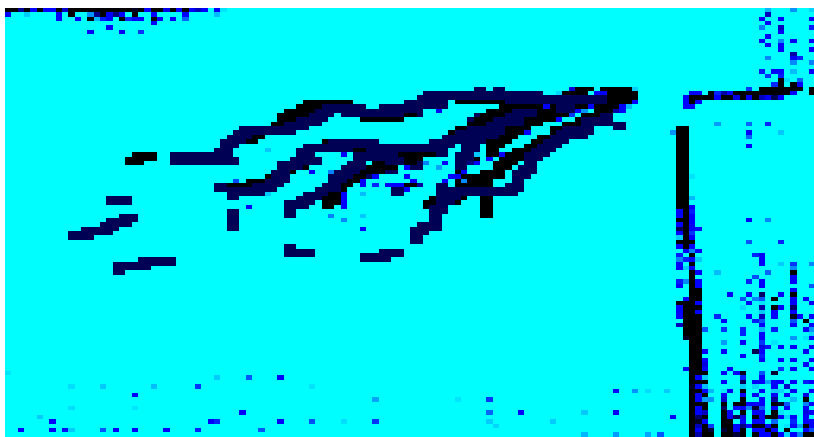
*WHAT WAS ACCOMPLISHED*

The research determined that breakup times and processes of viscoelastic liquids are very different from those of water. An increase in viscosity—due to the presence of chemical/biological (CB) agents—results in an increase in “threading,” which increases droplet size and mass in droplet versus that in vapor. This is illustrated in the figure, in which air at Mach 3 is flowing, from right to left, out of the orifice on the right. A droplet of a viscous liquid, simulating a CB agent dissolved in water, and falling from above, has just hit the supersonic air stream and is breaking up into threads in the center of the figure.

This research is leading to an improved capability to predict the dispersion of CB agents spilled from incoming theater missiles upon interception. Under the guidance of the Army’s High-Altitude Working Group, theory has been transferred from the university to SAIC, which has used it as the basis for the CASCADE model to calculate viscous liquid breakup and hence CB dispersion from intercepted theater missiles for the Missile Defense Agency.

*WHY IT IS IMPORTANT*

Iraq’s use of Scud missiles during the Gulf War brought to public attention the need to know what happens to biological or chemical agents contained in such missiles after their interception. To determine what happens requires that we understand how non-Newtonian liquids break up into vapor and mist when suddenly exposed to supersonic (up to Mach 6) airflow at high altitudes.



*Mathematical simulation of viscous-liquid breakup in Mach 3 airflow*

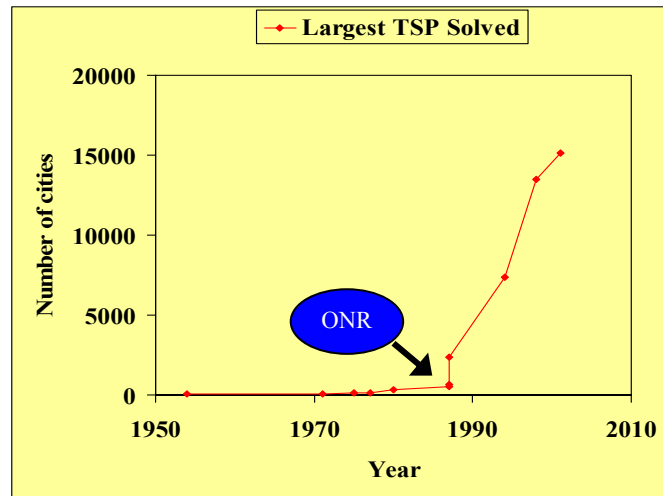
*MATHEMATICS AND COMPUTER SCIENCE: NAVY (ONR)*  
*THE TRAVELING SALESMAN PROBLEM (OR, HOW TO SOLVE LARGE, DIFFICULT COMBINATORIAL OPTIMIZATION PROBLEMS)*

*SUMMARY*

Researchers at Princeton University developed a mathematical technique that provides the ability to solve much larger optimization problems.

*WHAT WAS ACCOMPLISHED*

The paradigm for optimization methods is the traveling salesman problem (TSP), in which a salesman has to visit a customer in each of a number of cities, without visiting any city twice. How does he do this in the minimum time possible? The largest such problem solved prior to this new algorithm consisted of 15,112 cities. The heuristic algorithm, which is based on “branch-and-cut” integer-programming technique, is capable of solving problems with up to 1,000,000 cities.



*WHY IT IS IMPORTANT*

The importance of this algorithm is that optimization techniques form the basis of many computer programs in such seemingly unrelated areas as data processing, where a nonlinear function may be fit to a given data set. The method can be used in crew scheduling, truck routing, Army helicopter modernization manufacturing process planning, portfolio optimization, multitarget tracking, and solvers in spreadsheets, to name but a few applications.

## *MATHEMATICS AND COMPUTER SCIENCE: AIR FORCE (AFOSR)*

### *LARGE-SCALE SCIENTIFIC SIMULATION: MULTICONSTRAINT PARTITIONING*

#### *SUMMARY*

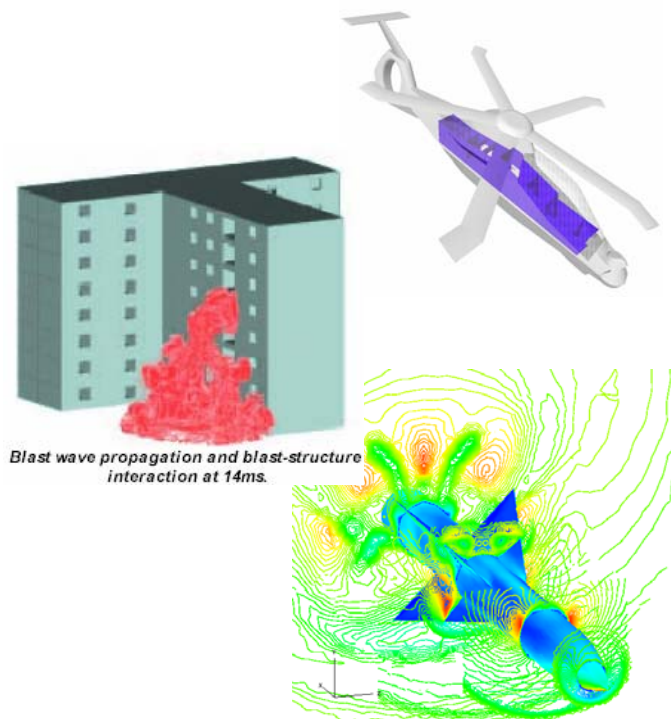
Mathematicians and computer scientists at the University of Minnesota have been developing the theory and algorithms for performing large-scale scientific computer simulations on modern parallel computers more efficiently. These large-scale simulations have extensive military applications and are used to solve problems in fluid flows, structural mechanics, wave propagation, electromagnetics, and heat transfer.

#### *WHAT WAS ACCOMPLISHED*

Large-scale scientific simulations are performed on modern parallel machines by breaking up a problem (partitioning) and distributing it over the computer processors to take full advantage of the sophisticated architecture. To maximize efficiency, this partitioning has to be performed in such a way that each processor performs the same amount of work (load balancing) and communication between processors is minimized. However, ensuring that such a partitioning is achieved is not straightforward. New, generalized, multiconstraint partitioning formulations, based on a subarea of discrete mathematics called *graph theory*, have been developed that allow for the rapid execution of very large simulations. This is accomplished by balancing not only the computations across processors but also the memory requirements. In addition, algorithms for solving these partitioning problems have been developed and incorporated into a software library that can be downloaded off the World Wide Web.

#### *WHY IT IS IMPORTANT*

Large-scale military simulations—once thought intractable—are now considered possible due to the advent of high-performance and parallel computers. However, traditional partitioning alone is not sufficient to model the underlying requirements of many current and emerging applications, especially in the area of high-performance scientific computing. The computations involved in areas such as blast wave propagation, crashworthiness testing, and earthquake simulation consist of a number of computational phases, each separated by an explicit synchronization step. The existence of these synchronization steps requires that each phase be individually load balanced. Doing so naively may lead to some processors having too much work during one phase of the computation and not enough work during another. Every processor must have an equal amount of work during all phases of the computation. This cannot be accomplished by current parallel computational models and partitioning algorithms.



*Three examples of large-scale scientific simulation using multiconstraint partitioning: helicopter modeling and visualization, blast wave propagation, and missile flight simulation.*

## *MECHANICS: ARMY AND AIR FORCE (USASBCC AND AFOSR)*

### *PRECISION AIR DELIVERY*

#### *SUMMARY*

The Precision Air Delivery (PAD) program was a 5-year research initiative led by the Air Force Office of Scientific Research and the U.S. Army Soldier and Biological Chemical Command to explore technologies for substantially improving the accuracy of high-altitude airdrop systems. The effort focused on improving the accuracy of payloads comparable in size to the Container Delivery System (CDS, ~2,200 pounds) delivered from high altitudes, where mission success is strongly dependent on release point accuracy and knowledge of the winds. Motivation for the program resulted from operational difficulties experienced in Bosnia and Kosovo while attempting to provide humanitarian assistance over hostile territory.

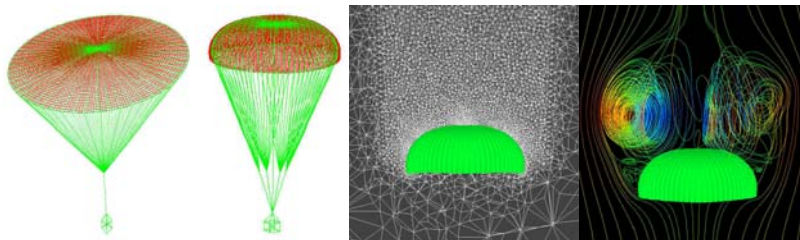


#### *WHAT WAS ACCOMPLISHED*

The joint Air Force/Army team identified three critical research areas for improving the effectiveness of high-altitude airdrop: (1) advanced low-cost decelerators, (2) all-weather wind sensing, and (3) automated computed aerial release point. Key advancements in these three areas are as follows:

- (1) *Affordable Guided Airdrop System (AGAS)*. The AGAS consists of a modified round parachute system with novel pneumatic muscle control actuators (fiber-reinforced braided tubes that contract when internally pressurized) that provide a maneuvering capability to maintain an accurate trajectory.
- (2) *Use of existing DoD mesoscale weather models to obtain high-resolution forecasts of winds in and around the drop zone*. The forecast model is augmented with data collected en route from dropsondes—small parachute systems that, on descent, relay their GPS position and local atmospheric conditions back to the aircraft.
- (3) *Automated Computed Aerial Release Point (CARP)*. Utilizing the wind/weather data, this capability allows the aircrew to replan an airdrop release point (or desired impact location) as updated weather, threat, or mission data become available. This represents a significant improvement over the current practice of computing the CARP prior to takeoff.

The PAD system, incorporating the integrated advancements achieved in all three key research areas, was successfully flight demonstrated in September 2001. The program has since transitioned into development by the U.S. Army Soldier and Biological Chemical Command, with Army and congressional investments in the program totaling \$4 million. Air Force participation in the project continues with the active involvement of the Air Mobility Command. An initial production of 10 systems with 70 supporting dropsondes is planned for the near future.



#### *WHY IT IS IMPORTANT*

Precision airdrop will increase the survivability of all USAF transport aircraft and provide new supply capabilities to the commander in the field.

## *MECHANICS: ARMY (ARO)*

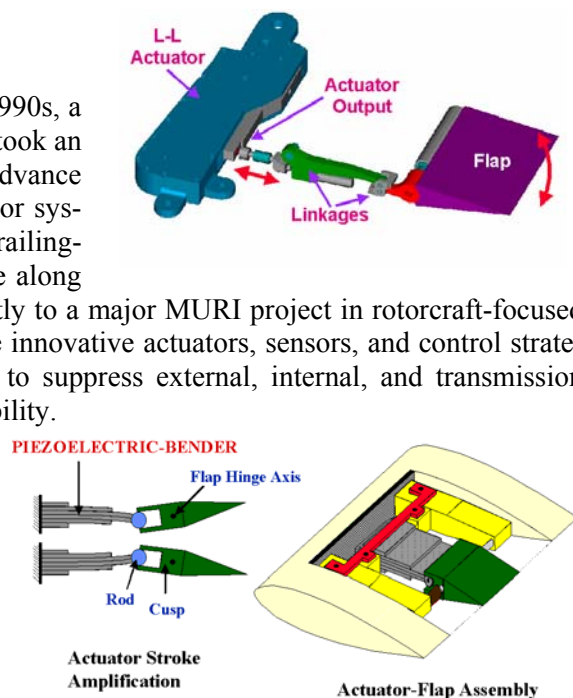
### *PIEZOELECTRIC ACTUATORS*

#### *SUMMARY*

In a University Research Initiative project in the early 1990s, a team of researchers at the University of Maryland undertook an innovative, interdisciplinary basic research program to advance smart structures technology as applied to helicopter rotor systems. The initial investigations of the actuation of a trailing-edge flap on a rotor blade and the twisting of the blade along its length through piezoelectric actuators led subsequently to a major MURI project in rotorcraft-focused smart structures research. The objective was to examine innovative actuators, sensors, and control strategies and to pursue high-payoff rotorcraft applications to suppress external, internal, and transmission noise and vibration, and to augment aeromechanical stability.

#### *WHAT WAS ACCOMPLISHED*

A key component of this research focused on the development of Froude-scaled smart rotor models—controllable twist models that incorporated embedded piezoceramic elements, and trailing-edge flap models that were actuated with smart actuators to minimize vibration and reduce blade-vortex interaction noise. A specially developed neural network controller for this rotor system proved capable of reducing the baseline vibratory hub load by 90 percent. Simultaneously, the neurocontroller could suppress the thrust, pitching moment, and rolling moment by more than 90 percent. These investigations revealed that flap deflection of  $\pm 6$  degrees at an excitation of four per revolution could be obtained at the Mach-scaled operating speed of 2,150 rpm through the use of an eight-layer tapered piezoelectric bimorph in conjunction with a bias voltage (unequal voltage applied to top and bottom piezoelectric layers).



*Top: A stack piezoelectric actuator in a housing and connected to a linkage mechanism used for transferring the linear actuator output to rotary-flap deflection.*

*Above: A layered piezoelectric actuator and its inserted configuration in a segment of a helicopter rotor blade with trailing-edge flap.*

The research has resulted in significant technology transfer to industry, which can now consider smart structures as a viable design option. In particular, the development of piezoelectrically based actuators for trailing-edge flaps was fundamental to the transition of smart-structures technology to a DARPA-funded smart rotor project. In collaboration with the University of Maryland, Boeing (Mesa, Arizona) developed a five-bladed smart rotor for the MD-900 Explorer helicopter featuring piezoelectrically driven trailing edge flaps. Initial wind tunnel tests and numerical analyses revealed that these smart rotor blades will deliver an 80 percent suppression of airframe vibration amplitudes and will reduce blade-vortex interaction noise by at least 10 percent. Additional benefits include aerodynamic performance improvements, increased payload and range, greater speed, stall alleviation, and enhanced maneuverability. The first flight test of the MD-900 smart rotor system was scheduled for late 2002.

#### *WHY IT IS IMPORTANT*

In the future, smart, actively controlled rotors may enhance the performance of the AH-64 Apache and RAH-66 Comanche helicopters and the V-22 tilt rotor aircraft. Potential transition of the adaptive-structures concepts is foreseen for uninhabited aerial vehicles.

## *MECHANICS: NAVY (ONR)*

### *TORPEDO LAUNCHWAY HYDRODYNAMICS*

#### *SUMMARY*

A decade-long basic research thrust within the community of turbulence researchers has led to the maturity of a challenging computational prediction method, large-eddy simulation (LES) of turbulent flows. LES was used at the Naval Undersea Warfare Center, Newport, Rhode Island, to address a critical problem with torpedo launching at high speeds. When other computational methods failed, LES was used to design circumferential chokes that reduced the backpressure in the launchway to allow normal weapon launching.

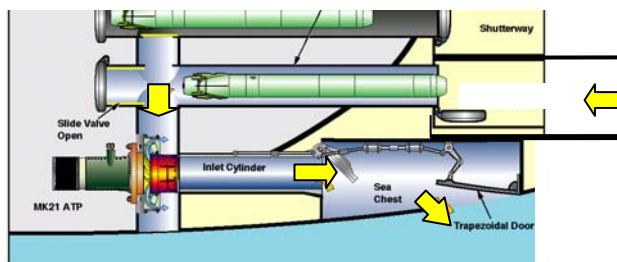
#### *WHAT WAS ACCOMPLISHED*

Large-eddy simulation of the turbulent flow into a Seawolf-class submarine's torpedo launchway during preparation for launch has been used to solve a problem with excessive pressure in the launchway at high ship speeds. A method was needed that would reduce the pressure before launch but would not interfere with the launch itself. Rings on the walls of the launchway, acting as roughness and thus pressure-drop elements, were selected for this purpose, but existing data on their effects were contradictory and unreliable. Predictions were needed for the design, but standard turbulence models in computational fluid dynamics codes are notably inaccurate for separated flow, such as that which would occur behind the rings.

LES, a leading-edge approach to computing turbulent flow, has been under development for more than a decade, including efforts at NUSC. Thus, LES was selected in an attempt to provide the needed information. Though LES is notable for being a more advanced and physically realistic approach to turbulence computations, it requires extensive computer resources and is normally a research method limited to simple configurations and low speeds. However, this application involved a fairly simple geometry—rectangular ribs—and the separated flow makes it less susceptible to low-speed effects. Several computations were performed to select the best arrangement of the ribs, and a prediction of the overall pressure loss was made. A temporary alteration to the launchway was constructed, an at-sea test was performed, and the pressure drop was measured. The agreement with the predictions was excellent, thus solving a critical problem for a major Navy asset.

#### *WHY IT IS IMPORTANT*

The removal of an upper limit on ship speed for the launching of torpedoes is necessary to maintain a large envelope of conditions for platform defense.



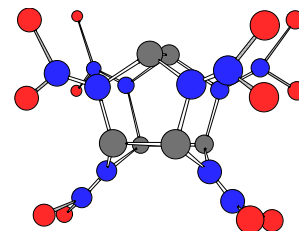
*Excessive backflow through the launchway inhibits proper weapon launch.*

## *MECHANICS: NAVY (NSWC)*

### *LOWER COST, IMPROVED QUALITY CL-20 ENERGETIC MATERIAL*

#### *SUMMARY*

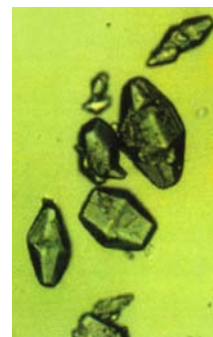
The objective of this project is to develop and implement advanced process technology for the manufacture of the energetic compound CL-20 and CL-20-based energetic compositions. A second objective is to establish the ability to manufacture an affordable and reproducible product at the industrial scale.



#### *WHAT WAS ACCOMPLISHED*

CL-20 (hexanitrohexaazaisowurtzitane), first synthesized in 1987 at the NAWC in China Lake under ONR basic research support, is the most energetic conventional explosive available for military use and is therefore being considered for a range of military weapons. Candidate applications span both propellant and explosive uses, including weapon systems such as the Standard Missile, Advanced Gun System, Advanced Land Attack Missile, and Precision-Guided Mortar Munition.

To bring this new energetic material to the warfighter, the Navy Manufacturing Technology (MANTECH) program is completing efforts to implement advanced process technology for the manufacture of CL-20 and CL-20-based energetic compositions that will improve sensitivity, product consistency, and quality while reducing costs. The Army and Navy CL-20 MANTECH programs are an integrated approach for making CL-20 production more affordable, predictable, and consistent. This effort includes the nitration, crystallization, and coating of CL-20. Under Army sponsorship, a process for the nitration of CL-20 has been optimized to produce CL-20 with greater than 99 percent purity at yields in excess of 90 percent. The Navy MANTECH project is focused on the crystallization of CL-20.



Two crystallization processes—evaporative and inverse precipitation—have been demonstrated in the laboratory at 50-gallon scales, and have now been successfully transitioned to the full 500-gallon production scale, where the optimization of the process conditions will occur. Major process parameters have been identified that influence CL-20 crystal quality and morphology. The effects of these parameters, as well as others, have been determined via a matrix of designed experiments. Full-scale (500-gallon) demonstrations of both crystallization processes will be completed this year at ATK-Thiokol, with technical support from NSWC Indian Head and NAWC Weapons Division.

#### *WHY IT IS IMPORTANT*

The use of CL-20 will increase lethality of weapon systems. Typically a 20 percent improvement in fragment velocity and shape-charge penetration over HMX explosive is realized with CL-20-based explosive formulations providing a greater lethality and lethal area. For explosively formed penetrator warheads, a 50–100 percent improvement in penetration has been demonstrated. The increased energy enables smaller payload packaging. This increase would translate into either increased mission capability, given the same number of weapon systems, or significant cost reduction because fewer weapons will be required to complete the same number of missions.



*Top: CL-20 structure  
Middle: CL-20 crystals  
Above: Submunition*

*PHYSICS: NAVY (ONR)**A THERMOACOUSTIC REFRIGERATOR FOR SHIPBOARD COOLING**SUMMARY*

ONR-sponsored research on chlorofluorocarbon (CFC)-free refrigeration has led to the development of TRITON, a thermoacoustic refrigerator, for shipboard cooling of compartments and electronics.

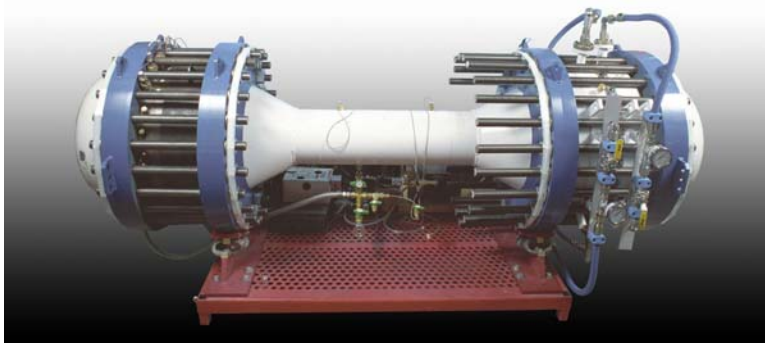
*WHAT WAS ACCOMPLISHED*

A thermoacoustic refrigerator uses a rolled plastic stack heat exchanger to transfer heat to another heat exchanger when its thermal core is placed near one end of an acoustic resonator. In the presence of a high-amplitude acoustic standing wave, the resonator's high-pressure helium is compressed and heated by the sound wave formed by the electrodynamic driver. The heat that builds up in the resonator is transferred to the stack. The gas is then pushed back by a reflected pressure wave and expands, cools down, and absorbs energy from the stack at a different location. The next wave compresses the gas and releases its heat back at the first location. This heat transfer cycle repeats through a chain (or bucket brigade) of wave nodes, and the sound waves in the device move heat through the refrigerator.

Researchers from seven different universities and federally funded research and development centers collaborated to transition this technology into TRITON. To optimize performance, research at the National Institute of Standards and Technology in the thermodynamics of gas mixtures in thermoacoustics was used in the development and choice of gases used in TRITON. Researchers at Penn State University developed performance models to demonstrate the scaling of the concept to the necessary size, while those at ARL–Penn State demonstrated the integration of the technology. Research at Los Alamos National Laboratory demonstrated that modifications to device shape could reduce low-amplitude acoustic losses, and subsequent research at the Naval Postgraduate School and UT–Austin demonstrated how such non-straight walled resonator shapes also lowered high-amplitude shock wave losses. Further work at Ohio University, the University of Mississippi, and Johns Hopkins University all contributed to significant improvements to the TRITON design. Nearly all of this work was funded by ONR under the Environmental Requirements Advanced Technology program.

*WHY IT IS IMPORTANT*

The principal benefit in this exciting new technology is CFC-free refrigeration and cooling capability achieved with minimal changes in the overall efficiency of the unit. Applications extend beyond the large-scale refrigeration of compartments and shipboard electronics. The Shipboard Electronics Thermoacoustic Cooler, a small-scale electronics rack chiller, has been developed using a nearly identical technique. Vast commercial opportunities exist for the technology—almost every application that uses CFC-based refrigeration today could use the new CFC-free refrigerator. Work still needs to be done to reduce the cost of this technology.



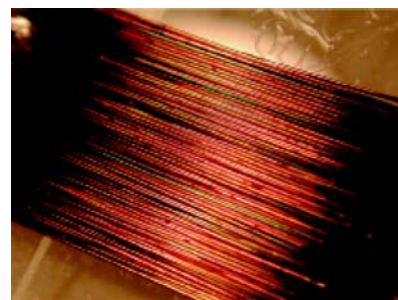
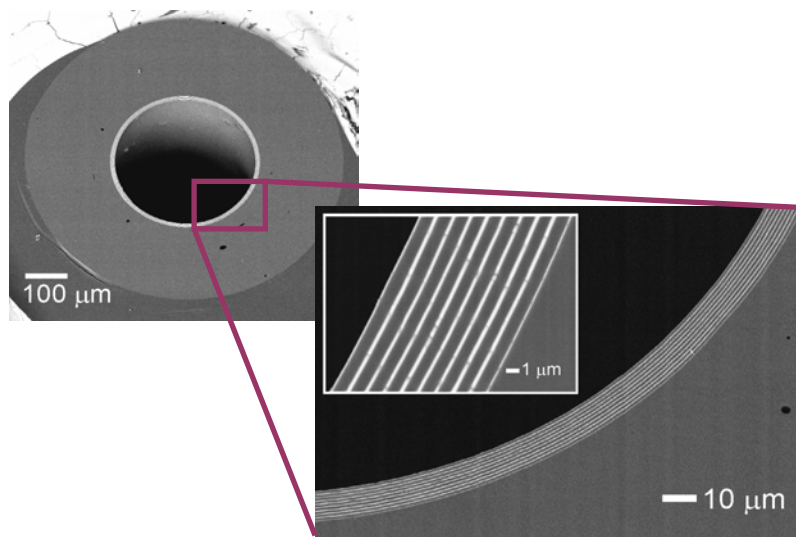
*The TRITON shipboard 3-ton acoustic refrigeration system*

*PHYSICS: ARMY (ARL)**PHOTONIC CRYSTAL FIBERS AS INFRARED REFLECTORS**SUMMARY*

ARO research into photonic crystals has led to the production of omnidirectional reflectors composed entirely of dielectric materials. Researchers at MIT have rolled infrared-reflecting photonic crystals into fibers capable of being woven into fabric.

*WHAT WAS ACCOMPLISHED*

Photonic-band engineering has promised to provide a means to tailor the flow of electromagnetic radiation simply by the pattern of holes in a dielectric or metallic material. One of the most intriguing applications of photonic-band engineering is the production of omnidirectional reflectors composed entirely of dielectric materials. For example, one-dimensional photonic crystals have been constructed and shown to be near-perfect reflectors over a broad range of wavelengths, polarizations, and incidence angles. Recently, researchers at MIT have rolled this one-dimensional photonic crystal into a tube and stretched it to form photonic crystal fibers that reflect radiation in the infrared region. These novel fibers can be woven into a soldier's uniform to help keep the soldier warm in cold climates and to help identify him to friendly combatants.



*Above: Photonic crystal fibers  
Left: Cross section of photonic crystal fiber reveals alternating layers of high- and low-index materials that have been rolled into the tubular structure of the fiber.*

*WHY IT IS IMPORTANT*

The production of novel fabrics composed of photonic crystals allows for the development of lightweight uniforms that efficiently keep soldiers warm in cold climates, or cool in warm climates. In addition, the reflective properties of these uniforms can be used to distinguish friendly forces from enemy combatants.

*PHYSICS: AIR FORCE (AFOSR)*  
*A NEW DIAGNOSTIC TOOL FOR LUNG IMAGING*

*SUMMARY*

AFOSR-sponsored research at Princeton University has developed techniques to construct three-dimensional images of human lungs.

*WHAT WAS ACCOMPLISHED*

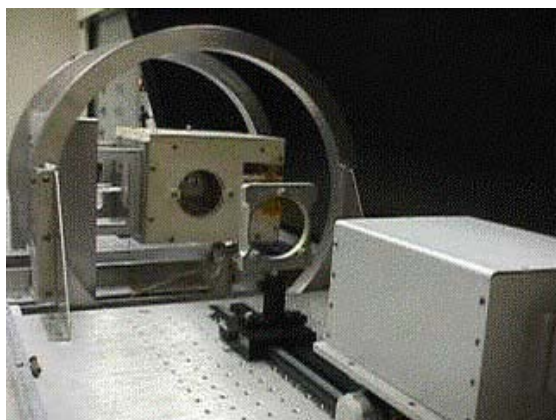
Researchers at Princeton University have produced atomic gas targets with polarized spins for nuclear and particle physics studies. They developed a method to optically pump spin-polarized alkali vapors, which can then polarize noble gases such as helium and xenon via efficient spin-exchange collisions. The method produces liters of gas with high levels of spin polarization (tens of percent) and storage times of a few hours.

Shortly after producing these large quantities of spin-polarized noble gases, collaborators at the State University of New York at Stony Brook and Duke University made magnetic resonance images of lungs. Medical trials at the University of Virginia have begun, using the technique to image a variety of pulmonary problems (e.g., asthma, emphysema, lung cancer, pulmonary embolisms) prior to surgery.

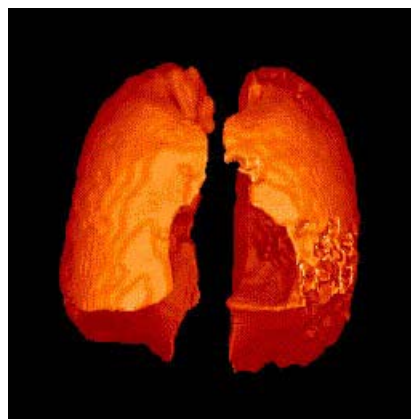
Highly spin polarized noble gases have also allowed researchers to develop new methods of non-destructive testing of structures (especially composite materials, which readily adsorb the noble gas), nuclear magnetic resonance (NMR) gyroscopes, and miniaturized atomic clocks.

*WHY IT IS IMPORTANT*

Before the development of this technique, the available medical diagnostics for lung problems were seriously lacking. In addition, since the gases are produced at such high levels of polarization, magnetic resonance imaging (MRI) signal levels are independent of the strength of the applied magnetic field. Thus, the large superconducting magnets needed to do conventional MRI are not needed. Future work should lead to the production of semiportable devices for polarized-gas imaging of lungs in forward-deployed hospitals.



*Optical spin-polarizing apparatus*



*Magnetic resonance image of a human lung*

## *TERRESTRIAL AND OCEAN SCIENCES: ARMY (ARO)*

### *BASIC RESEARCH ENABLES TACTICAL MOBILITY ANALYSIS*

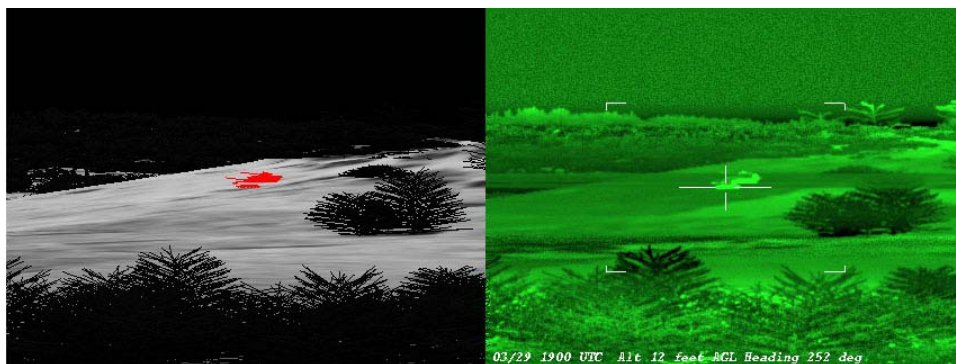
#### *SUMMARY*

By previewing realistic forward-looking infrared (FLIR) scenes, as opposed to the usual topographic map, rotary-wing pilots will improve assessment of routes and attack-by-fire positions using a database of the actual terrain, predicted weather, and state-of-the-ground conditions. This will directly affect mission planning and rehearsal by allowing pilots to rehearse their night missions, incorporating actual weather and state-of-the-ground conditions (i.e., wet, snow covered, grass).

#### *WHAT WAS ACCOMPLISHED*

In the early 1990s the Army supported basic research on the processes and properties of snow, snow-atmosphere energy, and mass exchange, and processes at and below the soil-snow interface. By the late 1990s, the Army's SNTHERM model became an academic standard with international regard and many related publications in peer-reviewed literature. Variants of SNTHERM have led to the recent SLTHERM model, which establishes new standards in explaining processes and properties in soil-snow and soil systems, and to the new FASST-C code, which parameterizes much of the sophisticated understanding gained by the earlier modeling efforts. The new FASST-C model forms the first version of dynamic state tools added to the Army's Combat Terrain Information System (CTIS Version 8.0). The software uses input from the Army's Integrated Meteorological System (IMETS) to gain weather variables used to drive the CTIS thermal model, which in turn predicts temperature and moisture profiles in the soil or snow at tactically relevant spatial resolutions.

The inclusion of a dynamic terrain-state model with CTIS marks the first time users will have the ability to predict ground condition, using physics-based codes and driven by weather data. As such, the Army has yet to experimentally measure the value to



the warfighter of this system within a system. Previous experiments on the terrain-state software subsystem, when applied to generating synthetic IR scenes as shown here for tactical mission rehearsal, showed marked improvement to battle position selection and target detection.

#### *WHY IT IS IMPORTANT*

A recently completed concept experimentation program sponsored by the Air Maneuver Battle Laboratory demonstrated a significant reduction in the selection of false targets as well as an improvement in target detection when pilots were able to view synthetically derived scenes prior to mission execution. Preliminary statistical results indicate an average 60 percent reduction in false targets, which results in a 70-second advantage in target detection over complex terrain.

## *TERRESTRIAL AND OCEAN SCIENCES: NAVY (ONR)*

### *DEVELOPMENT OF AUTONOMOUS UNDERWATER PLATFORMS*

#### *SUMMARY*

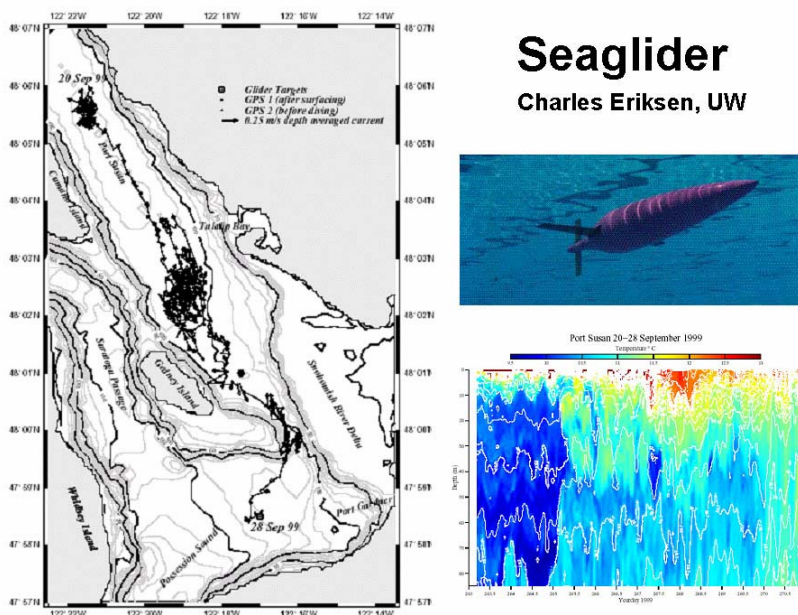
With simple, low-power sensors, Seaglider is capable of remaining at sea for several months and transmitting data to shore using satellite communications systems. In a recent test of stationkeeping, Seaglider was able to maintain station with 1-km accuracy for several days within the energetic Strait of Juan de Fuca.

#### *WHAT WAS ACCOMPLISHED*

Sampling the ocean from ships and other forms of manned platforms is expensive, time consuming, and conspicuous. While many situations call for having man in the loop, many routine ocean observations can be made without the direct control of human hands. Many of these observations are required to assess and predict the state of the ocean in denied areas and to conduct autonomous operations that increase mission efficiency and decrease threat. For this reason, the Navy is investing in autonomous, instrumented platforms that are capable of collecting key ocean observations covertly over long periods of time (several hours to several months). Some of these technologies are powered by conventional propellers while others have very low acoustical signatures and glide from one location to another by changing buoyancy. Sensor and navigation control can be either an autonomous, predetermined operation or one that is updated periodically using acoustical, RF, or satellite-based communications.

#### *WHY IT IS IMPORTANT*

The technology has been demonstrated, and a variety of platforms are becoming available as off-the-shelf products. Much of the current work is directed at sensor development, various communications approaches, and sensor miniaturization, and work needs to continue in learning how to deploy an autonomous network of sampling platforms. While manned platforms will likely always be a necessary component of ocean sampling, many acknowledge that autonomous platform technology has the potential to revolutionize how the global ocean is viewed and monitored.



*Seaglider, developed by Charles Eriksen, University of Washington Applied Physics Laboratory, is an autonomous ocean observation platform that uses buoyancy changes to move from one location to another.*

## **CHAPTER VII**

### **MULTIDISCIPLINARY UNIVERSITY RESEARCH INITIATIVE**

The Multidisciplinary University Research Initiative (MURI) program is the principal element of the DoD University Research Initiative (URI). The URI is the DoD initiative sponsored by the Office of the Director of Basic Sciences, Office of the Deputy Under Secretary of Defense for Laboratories and Basic Sciences (OUSD(LABS)), to enhance universities' capabilities to perform basic science and engineering research and related education in areas relevant to national defense.

The MURI program supports university teams conducting research that involves more than one traditional science and engineering discipline. Multidisciplinary teams under one project leader promote cross-fertilization of ideas and direct their efforts toward a common practical goal. In addition, these teams accelerate the transition from research to application and, in the process, help train graduate students in science and engineering fields appropriate to DoD needs. The MURI team efforts complement other DoD programs that support university research, principally through single-investigator awards.

Typically, the MURI awards are for a basic period of 3 years, with 2 additional years possible as options, bringing the total award to 5 years. The award generally ranges from \$500,000 to \$1 million per year. By contrast, single-investigator awards typically amount to about \$100,000 per year and may be limited to 1 year. With award levels to MURI teams so much higher, MURIs are in a position to provide significantly more funding for critical university research infrastructure than can traditional, single-investigator projects. This funding includes training for more graduate students and acquiring or modernizing equipment needed to conduct the proposed research, equipment that is usually expensive and that would not be possible to provide in a single investigator project.

DoD encourages proposals from university consortia because research in multidisciplinary topics requires teams with strengths in a multitude of science and engineering fields, which may not reside at a single university. Given the relatively large size of MURI awards, fusion of ideas can be achieved more readily when investigators with different backgrounds and disciplines collaborate toward a common objective rather than work independently. Primary consideration for selection of the awards is given to the relevance and potential contribution of the research to the defense mission as well as the quality and scientific merit of the research. Interaction with industry is encouraged with a view toward rapid transition of the research results to technology development.

The URI was initiated in 1983 to fund interdisciplinary research at universities. As the program developed, it was expanded to include multiuniversity teams and to encourage industry interactions where appropriate (but without DoD funding to the industry participants). These larger grants also made it possible for the universities to acquire and share more modern and expensive instrumentation than would have been possible through single-investigator grants. Currently there are 181 ongoing MURI projects that were started in FY97 through FY02, covering many areas of multidisciplinary research that are critically important to DoD.

In FY02, the MURI programs focused on four broad research themes:

- *Energetics*—deals with the scientific understanding of energy and its transformations to include production, storage, release, and conversion from one form to another. Multidisciplinary approaches involving chemistry, physics, biology, mathematics, and engineering sciences are being emphasized. DoD could realize potential high payoffs from this research in the areas of explosives, propulsion, power, and warrior readiness.
- *Multifunction materials*—deals with the scientific understanding needed to develop materials able to perform more than one function, such as sensing, electrical or optical conduction, flexible (adaptive) response to stimuli, structural integrity, durability, biodegradability, and manufacturability. Multidisciplinary approaches involving mathematics, chemistry, biology, physics, and engineering sciences are being emphasized. DoD could realize potential high payoffs from this research in the areas of adaptive response to changing environments, propulsion, sensors, munitions, warrior readiness, weapon platforms, autonomous systems, and information flow.
- *Synergistic sensing*—deals with the scientific understanding needed to develop a variety of new sensors and techniques for fusing sensor signals to provide a synergistic “picture” of the operational environment. Multidisciplinary approaches involving physics, chemistry, biology, mathematics, computer and information sciences, and engineering sciences are being emphasized. DoD could realize potential high payoffs from this research in the areas of battlefield awareness, combating terrorism, chem/bio defense, warrior readiness, information flow, decisionmaking, and autonomous systems.
- *Control for adaptive and cooperative systems*—deals with the fundamental principles needed to develop new methodologies required for high-precision navigation as well as precision timing and control of highly dynamic groups of both human-operated and autonomous vehicles and robots. Multidisciplinary approaches involving mathematics, physics, computer and information sciences, and engineering sciences are being emphasized. DoD could realize potential high payoffs from this research in the areas of adaptive command and control of swarms of uninhabited vehicles, robots, and satellite clusters.

The potential payoffs described above are summarized in Table VII–1.

The FY02 MURI competition resulted in 26 awards to 22 academic institutions in 19 topical areas of basic science and engineering. Each MURI award usually involves many investigators on the team from several universities. The following listing of FY02 MURI awards provides an illustration of the breadth of the MURI program and its multidisciplinary nature (only university team leaders are shown in the parentheses):

- Adaptive Coordinated Control in the Multi-agent 3-D Dynamic Battlefield (University of California at Berkeley)
- Energetic Materials Designed for Improved Performance and Low Life Cycle Cost (Oklahoma State University)
- Molecular Design of Cost-Effective Multifunction Designer Materials (Virginia Polytechnic Institute and State University)

**Table VII–1. Potential Payoff of MURI Program Research**

Areas of Potential High Payoff to DoD	Research Themes			
	Energetics	Multifunction Materials	Synergistic Sensing	Control for Adaptive and Cooperative Systems
Adaptive C <sup>2</sup> of Swarms of Uninhabited Vehicles, Robots, and Satellite Clusters	•		•	•
Adaptive Response to Changing Environments		•		•
Autonomous Systems	•	•	•	•
Battlefield Awareness			•	•
Chemical/Biological Defense			•	
Combating Terrorism			•	
Decisionmaking			•	
Explosives	•		•	
Information Flow		•	•	
Munitions	•	•	•	
Power	•			•
Propulsion	•	•		•
Sensors		•	•	•
Warrior Readiness	•	•	•	
Weapons Platforms	•	•		•

- Flexible Membranes Exploiting Selective Active Transport (University of Cincinnati)
- Real-Time, Explosive Specific Chemical Sensors (Johns Hopkins University, University of Puerto Rico)
- The Science of Land Target Spectral Signatures (Georgia Institute of Technology)
- Control of Adaptive and Cooperative Systems (Stanford University)
- Enabling Technologies for Optical Clocks (MIT, University of Colorado)
- Renewable Logistic Fuels for Fuel Cell Power Sources (Colorado School of Mines)
- Adaptive System Interoperability (University of Illinois at Urbana-Champaign)
- Adaptive Materials for Energy Absorbing Structures (Harvard University, UC San Diego)
- Scalability of Networked Systems (University of Maryland, Cornell University)
- Design of Multifunction Materials (Georgia Institute of Technology)
- Integrated Nanosensors (UC San Diego, Carnegie Mellon University)

- Multidimensional Sensing and Spectroscopy (Northwestern University, Georgia Institute of Technology)
- Biomolecular, Sub-cellular RF Sensing (Old Dominion University, Purdue University)
- Complex Adaptive Networks for Cooperative Control (University of Illinois at Urbana-Champaign)
- Biosynthetic Methodologies for Energetic Ingredients and Other High Nitrogen-Containing Compounds (Michigan State University)
- Detection, Classification Algorithms for Multi-Modal Inverse Problems (Duke University).

The FY03 MURI program will be focusing on topical areas that are closely matched to the Strategic Research Areas listed in [Chapter VI](#) and the DoD transformation initiatives. Awards are expected to be announced in March 2003 in the following 12 topics:

- Minimal organotypic cell systems
- Self-assembling multifunctional ceramic composites
- Fundamental theoretical/experimental molecular science underpinning fuel cell systems
- Integrated artificial muscle, high-lift bio-hydrodynamic and neuro-control for biorobotic autonomous undersea vehicles
- Direct thermal-to-electric energy conversion
- Image processing sensors for autonomous vehicles, robotics, and remote sensing
- Hybrid inferencing from fused information
- Biologically enabled synthesis of ceramic microdevices
- Active-vision for control of agile maneuvering aerial vehicles in complex 3-D environments
- Direct nanoscale conversion of biomolecular signals into electronic information
- Synthesis of long-chained sequence-controlled heteropolymers
- Laboratory instrumentation design research.

MURI has been a very successful program. Significant technical discoveries and innovations have transitioned to support defense applied research and have been inserted in major systems supporting the warfighter. A recent publication, *Defense Science and Engineering Research: Accomplishments of the DoD Multi-disciplinary University Research Initiative, Legacy of the 1990's, Foundation for the Future* (Reference 15), describes some of the successful outcomes of this very productive program.

## CHAPTER VI

### STRATEGIC RESEARCH AREAS

The DoD Basic Research Program supports a broad range of activities spanning many scientific disciplines. The results of these extensive fundamental research efforts provide a sound technical foundation for meeting both the recognized current U.S. defense requirements as well as projected but less well defined future needs. To focus attention on a few of the most exciting research areas that offer significant and comprehensive benefits to our national peacekeeping and warfighting capabilities, the following six Strategic Research Areas (SRAs) were established in 1995. The SRAs are periodically reviewed and strengthened. The current SRAs are described in this chapter.

- *Bioengineering Sciences*—research to demonstrate novel synthetic materials, processes, and sensors through advanced understanding and exploitation of design principles found in nature.
- *Human Performance Sciences*—research to enhance human performance through advanced systems that can sense, analyze, learn, adapt, and function effectively in uncertain, changing, and hostile environments in achieving the mission.
- *Information Dominance*—research to provide fundamental advances enabling seamless and timely integration of large quantities of multimedia, multimodal information (speech, data, imagery, text, video, etc.); robust, secure, and interoperable computing; and rapid and secure transmission over pervasive, distributed networks of heterogeneous command, control, communications, computers, intelligence, surveillance, and reconnaissance (C<sup>4</sup>ISR) systems.
- *Multifunction Materials*—research to demonstrate advanced capabilities for modeling, predicting, controlling, and optimizing the dynamic response of complex, multi-element, deformable structures used in land, sea, and aerospace vehicles and systems.
- *Nanoscience*—research to achieve dramatic and innovative enhancements in the properties and performance of structures, materials, and devices that have controllable features on the nanometer scale (i.e., tens of angstroms).
- *Propulsion and Energetic Sciences*—research to exploit new concepts to achieve significant improvements in the performance of compact power sources and power-consuming devices through fundamental advances relevant to current technologies.

These SRAs were selected on the basis that they (1) support DoD missions, (2) have the potential to provide significantly enhanced capabilities for the peacekeepers and warfighters, (3) are highly visible and broad areas of substantial DoD investment, (4) are crossdisciplinary and multidisciplinary in nature, (5) require sustained investment over a long period of time, and (6) have the potential for major scientific breakthroughs. The SRAs cut across the Reliance Basic Research Areas to provide focus on areas in which interdisciplinary work should have major payoffs for DoD.

The Scientific Planning Group (SPG) and the SRA coordinating committees provide coordinated tri-service oversight for research in these areas. Research activities in the technical disciplines tend to concentrate on the scientific disciplines involved, whereas the SRAs tend to

focus on interdisciplinary approaches to enhance DoD capabilities. The SRAs tend to be multidisciplinary, as shown in Table VI–1.

**Table VI–1. Correlation of Strategic Research Areas and Scientific Disciplines**

Scientific Disciplines	Strategic Research Areas					
	Bioengineering Sciences	Human Performance Sciences	Information Dominance	Multifunction Materials	Nanosciences	Propulsion and Energetic Sciences
Atmospheric and Space Sciences			•			
Biological Sciences	•	•		•	•	
Chemistry	•			•	•	•
Cognitive and Neural Science	•	•				
Electronics	•	•	•	•	•	•
Materials Science	•			•	•	
Mathematics and Computer Sciences	•	•	•		•	
Mechanics		•		•		
Physics				•	•	•
Terrestrial and Ocean Sciences			•			

These six SRAs reflect the high-payoff potential of multidisciplinary research in various scientific disciplines and the continuing importance of such research in achieving critical new capabilities for many types of military missions. Each SRA, together with its associated research thrusts, is discussed below. Current funding levels for the SRAs are summarized in [Section G](#) at the end of this chapter.

## **A. BIOENGINEERING SCIENCES**

### **1. Objective**

Research in Bioengineering Sciences involves biologically derived and biologically inspired materials, processes, sensors, or systems providing the basic foundation and enabling capabilities for exploiting the interface of biological sciences with the physical and engineering sciences for advances in biotechnology of use to the military.

## 2. Thrusts

- Energy conversion
- Sensing and information processing
- Materials and processes.

## 3. DoD Applications

- Environmental adaptability.

The integration of the biological sciences with the physical sciences and engineering to create a hybrid field called Bioengineering Sciences establishes a conceptual approach for exploration and characterization of nature's secrets and exploitation of the underlying fundamental principles for military applications. As a Strategic Research Area, Bioengineering Sciences seeks to benefit from the direct manipulation of a process of biological origin or from engineered exploitation that derives product or process design or function from a naturally occurring system. The overall approach is one that incorporates, in a wholly integrated manner, the most advanced and diverse conceptual and experimental tools of a number of scientific disciplines, including biology, materials science, chemistry, physics, electronics, mathematics, and computer sciences, as well as more recently evolved, internally integrated disciplines that have grown out of these, such as genomics. Bioengineering Sciences could be on its way to becoming a scientific discipline in its own right.

For the conversion of energy from one state to another, as well as for storage, nature offers examples of a variety of biochemically based macromolecular systems. Some of these materials permit exceptionally efficient transfer of energy over a very wide range of performance durations and are very likely to provide useful insight to ongoing efforts enabling eventual development of compact and other niche-use power systems. Possible areas of investigation include bioenergetics, storage and transfer, nanoscale biomechanics, and biomolecular and cellular photodynamics. For example, in cells, mechanochemically active biomolecular machines generate piconewton force and provide highly regulated movement at the nanometer scale. By virtue of the biomimetic insight and supramolecular engineering strategies to be gained by studying the chemistry and physics of these extraordinary biomolecular motor systems, the promise of unique contributions to the miniaturized and specialized field of microsystems power and actuation seems great. Likewise, contributions by way of conceptual insight would be expected in the area of robust biocatalytic processes for energetics, including fuel generation or processing, or in the area of bio-microelectromechanical systems (BioMEMS), as would contributions in photodynamic energy conversion wherein nature exhibits the advantage of exquisite macromolecular systems for exceptionally efficient capture and harnessing of the energy of separate parts of the electromagnetic (EM) spectrum.

For sensing and information processing, biological systems have exquisite and highly integrated sensing capabilities that allow rapid and selective recognition and signal processing for detection and classification of target molecules, men, or machines in noisy and cluttered environments. Sensors designed using biological principles offer the possibility of novel classes of sensors, far more sensitive and rapid than anything available today, along with seamless integration of sensory information from multiple sensory modalities, as occurs in animals. Additional insight should be gained to the variety of signal transduction possibilities available, including how they might be used to incorporate similar concepts in engineered systems (e.g., “sense-and-

respond” processes operating in the biological world for signature control). Likewise, studies of the means by which nature efficiently stores and processes information at the biomolecular and cellular levels would be expected to provide unique and highly valuable insight to possibilities for a whole new class of biologically based or biologically inspired computation methodologies, or “biocomputation.” The hierarchical arrangement of information in biological systems, by virtue of its adaptability and flexibility, should attract an infusion of new ideas into this area, particularly when reproduction and housekeeping (i.e., living) in a cell or higher organism is viewed as the result of applying simple operations of cutting, splicing, and copying to initial information encoded in a deoxyribonucleic acid (DNA) or other high-fidelity macromolecular sequence.

There are numerous examples of materials that occur in biological systems that exhibit remarkable properties. A unique feature of these materials is that their functionality is derived from fabrication processes consisting of several levels of self-assembly involving molecular clusters organized into structures of different length scales and exhibiting self-replication, repair, and regulation. Many of these materials provide lessons from nature on unique supportive and protective structural materials, as well as entirely new functional materials. For engineering applications in systems useful to the military, there is much to be learned from how nature accomplishes other physicochemical feats, such as generation of hybrid structures encompassing the organic–inorganic interface, particularly to gain insight into the construction of functionalized biological–nonbiological membranes and surfaces for transport, separation, and other applications. Knowledge of the fundamental biochemical principles underlying inter- and intramolecular association in complex biological macromolecules, and of how these contribute to folding mechanisms for generation of multifunctional supramolecular structures, is key to exploiting successes in directed evolution, genomics, proteomics, metabolic engineering, and other biotechnology for use in new enabling technology for advanced industrial chemical processing and “materials by design” capabilities—that is, materials by *biomimetic* design rather than by *ab initio* quantum mechanical design. Understanding better the means by which the repertoire of 20 natural amino acids might be expanded to include nonnatural amino acids with interesting physical properties, perhaps by engineering ribosomal biosynthesis, would contribute new ways to accomplish high-fidelity molecular manufacture of peptide polymers exhibiting material characteristics of use to the military. Related to this is the study of other synthetic and degradative processes in nature, enabling biologically derived or biologically inspired methods for producing materials in aqueous solution, at ambient temperature, to effect pollution-free (or at least pollution-minimized) synthesis and, by application of these principles, the cleanup of hazardous wastes.

Because many animals exhibit extraordinary agility and control in difficult environments, these physical features and underlying concepts not only lend themselves to incorporation in engineering of new vehicles and platforms, but also provide fundamental principles for improved warfighter adaptability to those same difficult environments. It is not at all unrealistic to envision application of lessons from nature in the form of particularly useful adaptive mechanisms learned from one animal species to enhancement of human performance, sustainability, and health. Thus, for example, human performance might benefit from better understanding of how the cognitive and perceptual interface might be manipulated, or of how physical augmentation and assist might be able to contribute to enhanced structure and function for human musculoskeletal operation under increased physical demands. Operational knowledge of macrobiological multifunctional structures and control mechanisms that contribute to system performance in the animal world promises to contribute to more effective design of engineered systems applicable to the human (e.g., in locomotion) as well as to areas such as robotics. Likewise, warfighter health might benefit from biologically derived or biologically inspired approaches to improved prophylaxis,

diagnostics, therapeutics, and other countermeasures against chemical or physical degradation of the human system. Advances in human genomics, immunology, and stem-cell biology, as well as greatly enhanced knowledge of chemical signalling, have given us a better understanding of how cells and tissues use various biochemical processes to effect maintenance of uncompromised physiological structure and function. These advances could in turn lead to entirely new medical approaches to use of the self-repairing or regenerative mechanisms existing in various organisms.

## **B. HUMAN PERFORMANCE SCIENCES**

### **1. Objective**

Provide theory and models of expert performance to enable technologies that maintain, augment, or reliably duplicate operator control of complex weapon systems.

### **2. Thrusts**

- Cognitive performance modeling
- Human–system interface
- Physiology of stress
- Distributed/collaborative decisionmaking
- Intelligent training.

### **3. DoD Applications**

- Robust command and control for future battlefields
- Multiechelon common operating picture
- Increased unit readiness.

Future military systems are expected to require many fewer yet more capable decision-makers working in geographically distributed flexible groups, informed by a common operating picture, to supervise semiautomated systems. This future goal is motivated largely by desires to reduce the considerable cost of maintaining a large pool of experts (technical training alone costs DoD tens of billions of dollars annually) while increasing the speed, accuracy, and survivability of force deployments. Multiple technologies will contribute to achieving this goal, but those impacting human situational awareness will benefit greatly from a fundamental understanding of human capabilities. This SRA enables technology innovations to maintain and enhance the cognitive readiness of military forces.

Thrusts in this area contribute to primary aspects of Human Performance Sciences. For example, fundamental work on modeling the decisionmaking capabilities of experts provides a basis for design of training systems, for technologies of decision aiding and intelligent agents, and for benchmarking expert performance essential to determining the impact of innovations across the design space of human-centric systems. Work on advanced concepts for human–system interfaces, which includes research on sensory and motor systems, contributes to high-bandwidth, error-free control by human operators that is robust to increasing workload demands or dynamic reallocation of function between human and machine. Research on stress physiology, including new tools for objective measurement of workload, contributes to discovery of stress

mitigation technologies—perhaps pharmaceutical in nature or provided through adaptive interface designs. Research on collaborative and distributed decisionmaking, which includes measuring the impact of social variables and leadership, provides a basis for scalable command architectures that dynamically adapt to changing workload or functional requirements. Lastly, research on intelligent training contributes to technologies for continuous training embedded in operational equipment, to adaptive interfaces through individualized coaching systems, and to the design and calibration of realistic synthetic forces used in large training scenarios and in modeling and simulation of command structures.

Multiple scientific disciplines contribute to progress in each thrust, from neuroscience and brain imaging in studies of perceptual-motor systems and stress physiology, through psychological cognitive task analysis in synthetic task environments for study of benchmark performance levels, to computer science and engineering approaches to modeling adaptive decision rules for intelligent tutoring systems and software agents for job aiding. As a result, research in Human Performance Sciences couples closely with work in information technology concerning network-centric warfare and information dominance, and work in biomimetics concerning intelligent automatic target recognition.

## **C. INFORMATION DOMINANCE**

### **1. Objective**

Provide fundamental advances enabling the collection, processing, computing, integration, dissemination, indexing, retrieval, storage, communication, networking, and display of large quantities of multimedia, multimodal information (speech, data, imagery, text, video, etc.) and ensuring robustness, security, and interoperability.

### **2. Thrusts**

- Critical infrastructure protection
- Information assurance
- Information protection and security
- Next-generation computing
- Sensor and information fusion.

### **3. DoD Applications**

- C<sup>4</sup>ISR
- Network-centric warfare
- Target detection, recognition, and acquisition
- Common and complete tactical picture
- Battlespace situation awareness
- Robust, secure, interoperable, and timely information sharing for collaborative planning and mission execution.

Research in Information Dominance provides the foundation for orders-of-magnitude increases in information processing capabilities by digital computers. Areas of research include software engineering to enable increased software productivity and reliability; high-confidence computing systems with assured composed behavior and information security; networks that provide reliable, secured, and robust quality of service; human-centered computing systems that can serve as knowledge repositories for information access, management, and application; and high-end computing that will lead to future generations of computers that are orders of magnitude faster than today's fastest supercomputers. Such high-end computing research will lead to advanced technologies and innovative computing architectures.

## **D. MULTIFUNCTION MATERIALS**

### **1. Objective**

Provide fundamental understanding for the development of advanced active materials that can adapt in real or near-real time to the changing environment in response to electric, magnetic, mechanical, thermal, and chemical stimuli and capabilities for modeling, predicting, controlling, and optimizing the dynamic response of complex, multielement, adaptive deformable structures used in land, sea, and aerospace vehicles and systems.

### **2. Thrusts**

- High-performance active materials (piezoceramics, relaxor ferroelectrics, shape memory alloys, etc.)
- Adaptive and reconfigurable structures with distributed sensors and actuators
- Multiscale computational design of structural materials with embedded functionality
- Materials with embedded electrical/magnetic/optical functionality
- Self-assessing and damage-mitigating materials
- Dynamic-resistance smart materials.

### **3. DoD Applications**

- Platform protection and resistance and vibration noise control in submarines and torpedoes
- Shape and flow control to reduce cavitation under water or dynamic stall in aerodynamics
- Stability augmentation systems for fixed-wing and rotary-wing aircraft
- Vibration suppression in weapon systems to improve pointing and tracking accuracy
- Conformal, load-bearing antenna structures and phased arrays
- Gross shape control of self-deploying space mirrors and antennas
- Smart skins for stealth applications in high-performance combat aircraft
- Defense infrastructure protection and threat reduction.

Multifunction materials and structures offer significant potential for expanding the effective operations envelope and improving certain critical operational characteristics for many DoD systems. To realize the full potential of smart materials and structures in military systems, DoD supports fundamental investigations that address active/passive structural damping techniques, advanced actuator concepts able to provide greater forces and displacements, embeddable and nonintrusive sensors, and smart actuator materials (e.g., piezoelectric and electrostrictive materials, ferromagnetic and other shape memory alloys, magnetorheological fluids). Research is focused on new material design and fabrication processes for actuators and sensors on the micron to millimeter scale, computationally accurate and efficient constitutive models for smart materials, advanced mathematical models for nonconservative and nonlinear structural and actuator response, robust hierarchical control with distributed sensors and actuators, structural health monitoring techniques, agile signature control to avoid detection, and concurrent, integrated structural design and control methodologies.

## **E. NANOSCIENCE**

### **1. Objective**

Achieve dramatic, innovative enhancements in the properties and performance of structures, materials, and devices that have controllable features on the nanometer scale (i.e., tens of angstroms).

### **2. Thrusts**

- Fabrication, synthesis, and processing of nanostructures
- Nanoscale characterization
- Novel phenomena and properties
- Nanodevice concepts.

### **3. DoD Applications**

- High-density information storage (terabits)
- Superfast computers
- Image and information processors
- Low-power personal communication devices
- Miniaturized sensor suits for surveillance
- Warfighter personal status monitors, especially chemical/biological
- High-performance, affordable nanocomposite structures
- Miniaturized robotics and uninhabited platforms, especially for Military Operations on Urbanized Terrain (MOUT).

The ability to affordably fabricate structures at the nanometer scale will enable new approaches and processes for manufacturing novel, more reliable, lower cost, higher performance, and more flexible electronic, magnetic, optical, and mechanical devices. Recognized applications of nanoscience include ultrasmall, highly parallel and fast computers with terabit nonvolatile

random-access memory and teraflop speed; image information processors; low-power personal communication devices; lasers and detectors for weapons and countermeasures; optical (infrared, visible, ultraviolet) sensors for improved surveillance and targeting; integrated sensor suites, including chemical and biological agent detection; catalysts for enhancing and controlling energetic reactions; synthesis of new compounds (e.g., narrow-bandgap materials and nonlinear optical materials) for advanced electronic, magnetic, and optical sensors; and significant life-cycle cost reductions in many systems through failure prevention. These applications will exploit exciting properties of nanoscale materials not predictable from macroscopic physical and chemical principles.

DoD support for nanoscience research is focused on creating new theoretical and experimental results involving atomic-scale imaging methods, sub-angstrom measurement techniques, and fabrication methods with atomic control that will provide reproducible material structures and novel devices. It also includes investigations of phenomena dominated by size effects or quantum effects. Since the traditional disciplines of physics, chemistry, biology, and materials are essentially indistinguishable at the nanoscale, interdisciplinary efforts are strongly emphasized. Scientific opportunities include understanding new phenomena in low-dimensional structures, nucleation and growth, self-organizing materials, site-specific reactions, elastic/plastic deformation, nanostructural materials, solid-fluid interfaces, and supramolecular materials. Nanoscience will contribute directly to the goals in the Bioengineering Sciences, Multifunction Materials, and Propulsion and Energetic Sciences SRAs.

## **F. PROPULSION AND ENERGETIC SCIENCES**

### **1. Objective**

Develop the fundamental understanding of energetic materials and energy conversion processes to meet future warfighter needs in portable power sources, propulsion, and high-power energy systems.

### **2. Thrusts**

- Energetic materials
- Energy conversion dynamics
- Efficient energy conversion.

### **3. DoD Applications**

- Portable power sources
  - Compact electrochemical power
  - Compact thermal-to-electrical power
- Advanced propulsion
  - Electrical propulsion for weapons and platforms
  - Missile propulsion
  - Hypervelocity weapons and platforms

- High-power energy systems
  - Warheads
  - Pulsed electrical power.

The military places extreme demands on the performance of an enormous spectrum of power and energy technologies. These technologies range from advanced propulsion and warheads for weapons to electrical power for ground, sea, and air systems, including compact electrical portable power for the individual warfighter. Research in power and energy can be generally classified under energetic science, with propulsion science being an important subset of energy conversion that also considers weapon and platform control, in particular, for hypervelocity weapons and platforms.

Although the commercial sector will provide some of the energy and power technologies for the military, the responsibility for advances in specialized areas such as warhead energetics, propulsion for hypervelocity weapons, and pulsed electrical power for directed-energy weapons resides almost exclusively with the military S&T community. Even with commercial technologies, additional directed S&T investments are often needed to further advance commercially acceptable capabilities to meet military operational performance parameters. Such investments are needed especially in the electrical power arena, where power and energy densities of military systems often far exceed commercial requirements. In addition, the military places stricter requirements on fuel properties and safety, which can have a tremendous impact on energy conversion technologies.

While the military needs in propulsion and energetics are broad, the underlying scientific research areas are fairly narrow: energetic materials, energy conversion dynamics, and efficient energy conversion. Although efficient energy conversion can be considered a subset of energy conversion dynamics, it is so critical to many high-energy systems that it deserves a separate classification. All three fundamental scientific areas apply to each of the military applications categorized here as portable power sources, advanced propulsion, and high-power energy systems.

#### ***a. Portable Power Sources***

This application focuses primarily on individual compact electrical power sources (<100 W) but also includes ultra-light-weight, compact field generators (500–5,000 W). While electrochemical S&T (e.g., batteries and fuel cells) continues to be a major contributor in this application category, innovative research in compact thermal energy conversion, such as microchemical systems, is opening new opportunities in thermal-to-electrical power generation. Novel approaches in direct-energy conversion (e.g., thermoelectrics and thermophotovoltaics) are also included in this category.

#### ***b. Advanced Propulsion***

This application encompasses electrical power for weapons, vehicles, and platform propulsion as well as thermal energetics for missile propulsion and hypervelocity weapons and platforms. Key scientific features of this category include understanding and controlling the energy conversion process to achieve both high performance and high efficiency, as well as developing new energetic materials for thermal propulsion systems and electrochemical materials for high-energy-density storage and high-power-density generation. Many of the energetic materials

developed for advanced propulsion are common to warhead energetics (e.g., nanoscale metal particles), where appropriate control of the energy conversion dynamics determines whether the material undergoes combustion (propulsion) or detonation (warhead).

***c. High-Power Energy Systems***

This application refers to warhead energetics and pulsed electrical power. For warheads, new energetic materials play a critical role, while a fundamental understanding of the initiation mechanism is needed to develop insensitive munitions and to control the detonation process. Pulse electrical power focuses on the physics of generating high-power electrical pulses for electromagnetic and mechanical applications, but also includes development of materials and concepts for electrical energy storage and delivery that far surpass the energy conversion dynamics necessary for portable power sources and advanced electrical propulsion.

**G. SUMMARY AND FUNDING**

The DoD Basic Research Program builds the scientific foundation for future warfighting and peacekeeping capabilities, and the long-range research supported in the Strategic Research Areas will lead to defense capabilities in various military systems and operations. These SRAs support the capability requirements described in various DoD planning documents such as *Joint Vision 2020* (Reference 5). Consideration of many projected research results for these areas relative to numerous specific technology objectives cited in the *Defense Technology Area Plan* (Reference 3) has served to underscore the pervasive importance of the SRAs to improving U.S. defense capabilities applicable to a wide range of military systems and operations. In managing the Basic Research Program, special attention is being given to these areas to help ensure that their great potential can be realized through subsequent technology and system development efforts. Identification of additional such areas will be sought in continuing reviews of basic research activities.

Funding data for basic research work supporting the SRAs is provided in Table VI–2.

**Table VI-2. Funding Profiles for Basic Research Supporting Strategic Research Areas (\$Millions)**

Service	FY02	FY03	FY04	Service	FY02	FY03	FY04
<b>Bioengineering Sciences</b>				<b>Multifunction Materials</b>			
Army	12.3	15.4	13.5	Army	1.2	1.2	1.2
Navy	29.0	29.4	29.6	Navy	6.5	6.5	6.5
Air Force	6.1	6.2	6.1	Air Force	1.5	1.5	1.5
Total	<b>47.4</b>	<b>51.0</b>	<b>49.2</b>	Total	<b>9.2</b>	<b>9.2</b>	<b>9.2</b>
<b>Human Performances Sciences</b>				<b>Nanosciences</b>			
Army	11.4	12.1	12.0	Army	20.0	23.0	20.0
Navy	18.5	12.2	14.5	Navy	22.0	31.0	31.0
Air Force	12.9	13.0	13.1	Air Force	9.0	9.1	9.2
Total	<b>42.8</b>	<b>37.3</b>	<b>39.6</b>	Total	<b>51.0</b>	<b>63.1</b>	<b>60.2</b>
<b>Information Dominance</b>				<b>Propulsion and Energetic Sciences</b>			
Army	21.0	21.0	21.0	Army	25.8	25.8	22.4
Navy	24.4	21.2	24.7	Navy	17.5	17.6	16.6
Air Force	9.3	9.3	9.3	Air Force	7.1	6.8	6.5
Total	<b>54.7</b>	<b>51.5</b>	<b>55.0</b>	Total	<b>50.4</b>	<b>50.2</b>	<b>45.5</b>

## **CHAPTER V**

### **BASIC RESEARCH AREAS**

The great majority of the scientific research work constituting the DoD Basic Research Program involves 12 technical disciplines:

- Atmospheric and Space Sciences
- Biological Sciences
- Chemistry
- Cognitive and Neural Science
- Computer Science
- Electronics
- Materials Science
- Mathematics
- Mechanics
- Ocean Sciences
- Physics
- Terrestrial Sciences

As mentioned in Chapter II, each discipline is coordinated by a Scientific Planning Group (SPG), except for two pairs of closely connected disciplines: (1) mathematics and computer sciences and (2) terrestrial and ocean sciences. Because of their close connection, each pair of disciplines is handled by one SPG, making 10 SPGs for 12 disciplines.

In this chapter, there is a brief description of each discipline along with a table showing specific service interests and areas of commonalities. The amount of funding currently being provided to each SPG is summarized at the end of this chapter in [Section K](#).

#### **A. ATMOSPHERIC AND SPACE SCIENCES**

Research in Atmospheric and Space Sciences develops the basic technical foundations for use in battlespace environment applications important to DoD. Work in meteorology (dynamical, physical, and modeling), space science (ground-, air-, and space-based), and remote sensing (active and passive) is conducted to support a broad range of DoD interests and activities. The products of these basic research (6.1) efforts and the accompanying 6.2/6.3 work undergo transition to operational military commands for use in weapon and surveillance platforms; planning of peacetime and warfighting operations; live and simulated training; and the specification, forecasting, mitigation, and modification of the battlespace environment.

For DoD to plan and conduct a truly comprehensive program of research across the broad spectrum of atmospheric and space sciences, however, is not fiscally and technically feasible. Therefore, DoD collaborates with other U.S. federal agencies and the international research community to enhance knowledge. Examples of cost-sharing and leveraging of work by other agencies include tropical storm research (Office of Naval Research (ONR) and National Oceanic and Atmospheric Administration (NOAA)); high-resolution meteorological modeling (Army Research Office (ARO), National Science Foundation (NSF), ONR, and NOAA); space physics research in the National Space Weather Program (Air Force Office of Scientific Research (AFOSR), ONR, NSF, NOAA, and NASA); atmospheric aerosols (ONR, Army Research Laboratory (ARL), and NASA); and boundary layer modeling (ARO and NOAA). In the international community, DoD sponsors scientific conferences, such as the DoD Battlespace Atmospheric and Cloud Impacts on Military Operations (BACIMO), and supports focused scientific workshops, such as Space Weather Week at NOAA's Space Environment Center in Boulder, Colorado. These conferences attract government, university, and industry researchers from all over the

world and help to ensure that this area of DoD basic research is highly leveraged and well-coordinated with other scientists in these fields.

Mission requirements for each service serve as focal points for supported research. For example, the Army emphasizes research in continental boundary layer dynamics, remote sensing of atmospheric state and content, and atmospheric effects on sensor systems. The Navy has responsibility for global- and theater-scale meteorology focused on the marine environment, including tropical cyclones, marine cloud processes, air–sea interactions, and coastal zone predictions. The Navy space program emphasizes space-based atmospheric physics, while the Air Force space program tends to emphasize ground- and space-based remote sensing, detection and tracking of missiles, and on-orbit satellite operations and survivability. Whenever possible, interservice collaborations and complementary science programs are well coordinated to serve common interests.

Basic research in Atmospheric and Space Sciences comprises work in three subareas: meteorology, space science, and remote sensing.

## **1. Meteorology**

In many military operations, weather determines the order of battle and meteorology represents a force multiplier. Safety of operations, logistical planning and execution, deployment of forces in and out of theater, and sensor and weapon performance are all influenced by weather conditions. For example, the employment of precision guided munitions (PGMs) is affected by clouds, humidity, and obscurations. Piloted military aviation and unmanned aerial vehicles (UAVs) are increasingly dependent on accurate forecast and specification of meteorological parameters. The dispersal of chemical and biological agents, or even humanitarian aid, depends on winds and humidity. Understanding the basic nature of atmospheric turbulence and cloud boundary layers affects the ability to predict the transport and diffusion of airborne effluents, aerosols, heat, and moisture. Therefore, DoD’s atmospheric research effort seeks to provide the basic understanding of global and theater weather needed to construct reliable prediction models used by operational military commands.

For blue-water operations, special attention is directed toward understanding the behavior and evolution of tropical cyclones in general and in the Western Pacific in particular, where DoD has the lead forecast responsibility for the United States. Plans are to improve our knowledge about motion (track), structure (size), and intensity (wind speed) of these important phenomena. The research program balances theoretical modeling, analytical case studies, and experimental observations while exploring the limits of forecast predictability. The overall goal of these research efforts is to provide the highest quality mission-tailored weather information, products, and services to our nation’s combat forces in peace and war—anytime, anyplace.

## **2. Space Science**

As demonstrated during recent and current operations, U.S. forces are increasingly dependent on DoD space assets. GPS navigational capabilities, critical in high-technology warfare, are the direct result of long-term and ongoing basic research in precision timekeeping and ionospheric physics. Precision time-interval and time-transfer technology are also required for precise targeting and synchronization of secure communications and other systems. Ionospheric and upper atmospheric neutral density research will address needs for improved GPS accuracies, precision geolocation of radio frequency (RF) emitters, and RF communications. A new naval optical

interferometer may provide positional accuracies of astronomical sources below the milliarcsecond level. These advances, combined with improved astrometric reference frames and continuing improvements in compact electronics, will support operational requirements for systems with increased precision guidance and autonomous satellite navigation. The high bandwidth and secure communications features of the Milstar satellites are the result of large 6.1 investments in radiation-hardened electronics, broadband communications, space weather specification and forecasting, and lightweight power generation. Continuing efforts in these areas, coupled with ongoing developments in mobile wireless band communications, will result in a new generation of smaller, lighter, and more affordable satellites.

The next generation and block upgrades of DoD missile early-warning satellites—the Space-Based Infrared System (SBIRS)—will not be possible without continuing investment in focal plane technology, onboard signal processing capabilities, and the ability to acquire and track very dim targets against highly cluttered backgrounds. The potential ability to exploit basic knowledge of plume signatures and varying background radiance in the design of spectrally agile electro-optical sensor systems may even enable the detection of cruise missiles from space-based platforms. Solar and heliospheric research is directed toward understanding the mechanisms for generation of solar extreme electromagnetic fluxes, solar flares, coronal mass ejections, and the propagation of these phenomena from the Sun to the Earth’s magnetosphere and ionosphere. The resulting ionospheric variability affects RF communications over a very wide range of frequencies. A better understanding of solar and space physics, and the ability to accurately forecast even earlier the effects of solar activity, is the goal of the interagency National Space Weather program (NSWP). The research results from the NSWP will enable civil industry and military commanders to effectively manage those space systems susceptible to temporary or permanent disruption from space weather, until the space environment has returned to a more benign state. Upper atmospheric neutral density is also a function of solar activity, and future research will result in improved specification and forecast of satellite drag, orbital tracking, and vehicle reentry times—improving the U.S. Strategic Command’s (STRATCOM) ability to maintain and upgrade its Space Object Catalog.

### **3. Remote Sensing**

Remote sensing measures and characterizes signals, environmental parameters, and target signatures critical to the performance of surveillance, acquisition, tracking, and hit-to-kill sensors and weapons. It also provides critical chemical/biological warfare support. In meteorology, wind profiler technology provides details regarding the fine structure of wind, temperature, humidity, and aerosols within the atmospheric boundary layer. Of special importance is the ability to model and predict marine refractivity profiles and surface base ducts.

Light detection and ranging (LIDAR) laser systems detect the motion and physical state of molecular and atomic-sized targets in the upper atmosphere. All-sky imagers and Fabry-Perot interferometers record the faint emissions of the ionosphere and upper atmosphere. These sophisticated instruments provide valuable information on the physics, chemistry, and dynamics of the lower boundary of the ionosphere and how it couples with the atmosphere. Adaptive optics techniques improve the ability of astronomical telescopes to observe artificial and natural near-Earth objects for space situational awareness, while allowing high-resolution measurements of the magnetic variations near the Sun’s surface that were never before possible. Sensitive radar transmitters and receivers allow us to obtain vertical ionospheric density profiles to help observe and forecast ionospheric scintillation.

The development of the Airborne Laser is highly dependent on basic research directed toward measuring and mitigating the effects of natural and induced atmospheric turbulence. Remote sensing for missile warning and subsequent track and kill will be greatly enhanced with the planned development of hyperspectral imagery techniques and associated automatic target recognition algorithms. The ability to use space-based electro-optical sensors to see through the lower atmosphere and clouds is increasingly important as the theater ballistic missile threat requires better all-weather capability and improved warning times for cueing tracking sensors. The threat of chemical and biological agents against military and civilian populations has led to increased emphasis on the development of biosensors with very precise response.

Service-specific interests and commonality in atmospheric and space sciences are presented in Table V–1.

**Table V–1. Service-Specific Interests and Commonality in Atmospheric and Space Sciences**

Subarea	Army (A)	Navy (N)	Air Force (AF)
<b>Meteorology</b>	Continental boundary layer Transport and diffusion Chemical/biological defense Clouds and obscurations	Marine boundary layer Maritime and coastal meteorology Major storms, worldwide, with particular emphasis on tropical cyclones Synoptic to mesoscale prediction	None
	<b>Areas of Common Interest:</b> coherent structures (A, N); subgrid scale parameterization (A, N); large eddy simulation (A, N); nested models of all scales (A, N); surface energy balance (A, N); cloud formation and processes (A, N); data assimilation (A, N)		
<b>Space Science</b>	None	Precision time Space-based solar observation Wave-particle interactions Astrometry	Ground-based solar observations Energetic solar events Ionospheric structure and transport Optical characterization
	<b>Areas of Common Interest:</b> neutral density (N, AF); ionospheric C <sup>3</sup> I impacts (A, N, AF); celestial backgrounds (N, AF); geomagnetic activity (N, AF)		
<b>Remote Sensing</b>	Fine-scale measurement of wind, temperature, and humidity fields and fluxes Chemical/biological detection and identification Atmospheric acoustics	Marine refractivity profiles, especially in coastal zone Aerosol modeling Convective and stratus clouds Air–sea interfacial flow	Thermospheric LIDAR profiles Near-Earth objects, asteroids, comets, and meteoritic dust Adaptive optics for space situational awareness Satellite laser ranging
	<b>Areas of Common Interest:</b> atmospheric profiles of temperature, humidity, winds, aerosol concentration (A, N); aerosol effects (A, N); atmospheric transmission (A, AF, N); radiative energy transfer (A, AF, N); contrast transmission (A, N); ionospheric scintillation (AF, N); solar radio and optical emissions (AF, N); airglow optical emissions (AF, N).		

## **B. BIOLOGICAL SCIENCES**

Research in Biological Sciences provides the fundamental knowledge and scientific underpinning for the innovative use of biology to produce unique materials and processes of military relevance; to increase economic and environmental affordability through entirely new approaches for manufacturing, maintenance, and logistics concerns; and to prevent, or greatly lessen, the deleterious effects of chemical, biological, and physical agents from interfering with

military operations. Basic research within this scientific discipline addresses structure and function across length scales ranging from the nanometer to beyond the meter, and exploits, while at the same time contributing to, advanced concepts and techniques in a number of other scientific and engineering disciplines. It ensures that force health protection and safety standards are based on solid scientific evidence. For nonmedical basic research in the Biological Sciences, joint planning activities related to the SPG for Biological Sciences provide for close coordination between the Army, Navy, and Air Force and enable each of these three services to concentrate their resources on “service-essential” program support with minimal duplication of effort. Thus, the Army is very active in research impacting the areas of chemical and biological defense and counterterrorism, the Navy pays particular attention to processes active in the marine environment, and the Air Force invests especially in better understanding the means to mitigate effects of non-ionizing radiation on the human. Likewise, to avoid duplication and optimize utilization of resources, biomedical 6.1 programs throughout the three services are closely coordinated through the Armed Services Biomedical Research Evaluation and Management (ASBREM) Committee. DoD basic research in Biological Sciences comprises three major subareas: molecular/cellular, systems/organisms, and biomedical.

## **1. Molecular/Cellular**

Understanding fundamental biological principles and processes operating at the cellular, subcellular, and molecular levels enables manipulation of underlying phenomena to provide contributions in a number of application areas of strong relevance to the three services and DARPA. Basic research on the mechanisms of action of enzymes, intracellular receptors, and cell membrane receptors and ion channel complexes; on cellular signal transduction and amplification pathways; and on energy transfer processes, provides useful input to the military for chemical and biological defense and energy management. For example, research here enables detection of trace chemical compounds, including explosives, nerve agents, and other chemical threat agents, environmental toxicants, and medical diagnostics. It serves as well to provide the military with unique advanced counterterrorism and battlefield capabilities for detection and identification of biological threats. Likewise, research on photodynamic and motor proteins and other specialized-function biological macromolecules, on self-assembly processes, on control of the bio-abio interface, and on cell-derived tools for synthesis, provides the strategies for design and the means for manufacture of advanced electronic, magnetic, and photonic materials for enhanced memory devices, revolutionary sensing capabilities, improved warfighter identification, and signature management; and of new structural and functional materials for individual sustainment, performance, and survivability.

## **2. Systems/Organisms**

Biological organisms, including the human, constitute a system of systems wherein basic research studies offer a route to ensure effective protection and functional efficacy of both the individual warfighter and engineered system, and to enable advanced communication between the two. The warfighter, who may include those in DoD concerned with homeland counterterrorism activities, is exposed to hazardous physical, chemical, and biological threats. Research on particularly useful adaptive mechanisms exhibited in one animal species may sometimes offer a means to enhancement of human performance, sustainability, and health in the face of such hazards. For example, research on hibernation and hypometabolic stasis promises to provide useful insight into enhancement of individual survivability in harsh environments and in response to

injury, and to provide novel endurance capabilities. Advances in human genomics and proteomics, immunology, and stem-cell biology—together with a greatly enhanced understanding of the systemic physiology and pharmacology of pathways for cell–cell signaling, metabolism, and regulatory networks—offer substantial promise for improving a number of aspects of individual warfighter survivability. Likewise, for platforms and other engineered systems, studies of biological systems provide a wealth of opportunities for developing (1) improved battlespace information capabilities based on principles of fully integrated multimodal sensing capabilities, (2) mechanisms of controlled stealth and individually tailored response to imaging, and (3) autonomous networked mobility.

### **3. Biomedical**

Biomedical research provides the fundamental basis for improving the military’s capability to prevent injury and disease, sustain the health of the force, and provide efficient and effective combat casualty care when necessary. Advances in immunology, toxicology, physiology, neuroscience, biochemistry, psychology, and molecular biology—all of which are directed toward the understanding of militarily relevant disease and injury processes and the development of new models for evaluation of countermeasures—will provide the warfighter with new options for increasing survivability and mission effectiveness on future battlefields. The knowledge gained will be applied to the development of novel drugs, vaccines, medical devices, health promotion and prevention procedures, medical diagnostics, and treatments for trauma and disease. For example, the use of genomic and proteomic analysis of pathogens and human responses to disease and injury is enabling the discovery of new antigens that can be exploited in vaccines for biological warfare agents and endemic infectious diseases, new biochemical targets for prophylactic and therapeutic drugs, and new molecular or genetically based diagnostic tests for infection and environmental toxic hazard exposure. Basic research also explores the causes of biomechanical injury and environmentally induced performance degradation to identify possibilities for improved training methods, safer equipment designs, and acclimatization strategies. As a final example, studies on the biological responses to traumatic conditions—such as hemorrhage, low blood flow, and poor oxygen delivery—will help to identify potential prognostic and diagnostic indicators that can be used to determine appropriate medical treatment. These indicators can also provide a basis for physiological response models that can, in turn, be integrated into intelligent life support systems.

Service-specific interests and commonality in Biological Sciences are presented in Table V–2.

**Table V–2. Service-Specific Interests and Commonality in Biological Sciences**

Subarea	Army (A)	Navy (N)	Air Force (AF)
<b>Molecular/Cellular</b> Processes and Materials Sensors Biodegradation Chemical and Biological Defense	Structure, function, and nanoassembly Nanoscale biomechanics and energy transfer Olfactory and integrated multifunctional sensing Sense-and-respond processes Microbial degradation of aromatic compounds	Marine molecular biology Bioadhesion Bioluminescence Fast biosensor arrays Cell-based sensing Computational biology Enzymatic synthesis of energetic materials	Molecular mechanisms of infrared biosensing Novel molecular and computational tools for toxicity prediction Biomolecular response profiling
<b>Areas of Common Interest:</b> bioengineering sciences including biomimetics and biomaterials (A, N, AF); biocatalysis (A, N, AF); chemical and biological defense (A, N)			
<b>Systems/Organisms</b> Physiology Toxicology	Adaptation and survivability Sustaining and enhancing soldier performance Differentiated bacterial communities Hibernation and hypometabolic stasis	Marine mammal physiology Biomimetic sonar Environmental impacts of loud sound Marine environmental microbiology Immunophysiology	Toxic mechanisms of military chemicals and mixtures Bioeffects of non-ionizing radiation Nonlinearity of low-dose bioresponses
<b>Areas of Common Interest:</b> none			
<b>Biomedical</b> Infectious Diseases Combat Casualty Care Military Operational Medicine Medical Chemical-Biological Defense	Pathobiology of CBW agents Nutrition and thermoregulation	Physiology and biology of underwater operations	None
<b>Areas of Common Interest:</b> molecular biology of humans and infectious agents; immunobiology for clinical management; vaccine and drug design; medical physiology, biochemistry, and toxicology; and psychobiology of human health effects (A, N)			

## C. CHEMISTRY

The essence of chemistry is to characterize and understand the composition and transformation of matter. Such research is critical to developing advanced materials for specific DoD applications, developing suitable processes for producing these materials in cost-effective ways, and controlling chemical reactivity relevant to numerous DoD systems and requirements. Examples of important DoD materials derived from chemistry include materials for protection against chemical weapons, novel propellants and power sources, anticorrosion materials and coatings, and development of novel materials for cooling. This ability to tailor material properties to meet DoD needs arises from an understanding, at the atomic and molecular levels, of the relationships between structure and properties. From a process perspective, understanding and controlling thermodynamics and kinetics of chemical reactions yields significant benefit to DoD. Chemical reactivity and dynamics play important roles in controlling combustion in fuels, decoys, and propellants—providing environmentally friendly or cost-effective processing methods for production of DoD materials and for control of fouling, corrosion, and degradation of various DoD platforms and systems. This understanding of atomic and molecular processes and properties established through chemistry research enables the design of components for military systems with optimal performance.

Responsibilities for topics within the Chemistry discipline of the Basic Research Program are distributed in accordance with service mission considerations. These coordinated programs retain the responsiveness to pursue new scientific developments and service needs. The Army continues to emphasize systems related to chemical and biological defense (permeability, reactive and catalytic polymers) and to elastomers because of the heavy use of rubbery components in land vehicles. Important Navy areas of concentration include special considerations due to the harsh marine environment. Areas of interest include adhesion and surface properties relating to ship antifouling coatings, novel cooling technologies, and understanding and mitigating effects of operation on ocean and shore environments. The Air Force emphasizes materials that maintain their integrity in extreme environments, corrosion chemistry related to aging aircraft, chemical lasers, and processes that affect operations in the atmosphere and in space. Topics of common interest are energetic materials (there is no civilian effort on which to depend), optical polymers for rapidly disseminating and displaying information to the warfighter, power sources for specific DoD applications, and very exciting forefront topics such as nanoscience and biomimetics. Recent emphasis in nanoscience exploits chemistry and will ultimately lead to new ways of storing and processing data as well as developing of materials with unusual mechanical and electronic properties.

Chemistry research within the DoD Basic Research Program is divided into two major subareas: materials chemistry and chemical processes.

## **1. Materials Chemistry**

Advanced materials play a key role in numerous DoD systems having widespread applications. Chemistry research focuses on the molecular design and synthesis of materials with properties that can be tailored to specific DoD requirements. Structure/property relationships are determined to enable the design of optimal material systems. In addition to the applications cited above, other widespread applications of materials chemistry research include the development of materials for marine and aerospace environments, strong and lightweight composite materials, novel electronic materials and devices, semiconductors, thermoelectrics, electrochemically active materials, and barriers for chemical and biological weapons.

## **2. Chemical Processes**

The ability to control the interaction between materials and their environments can be exploited for many DoD applications. Some of the areas where this work impacts DoD operations are controlling friction and adhesion, corrosion, signatures, the fate and transport of chemicals, and the release of energy. Molecular processes are also being exploited to develop compact fuel cells as portable, clean power sources; to develop chemical lasers for directed-energy weapons; to control ignition and detonation of munitions; to sense and sequester contaminants in situ; and to store energy in propellants.

Army research on polymers and elastomers continues to develop materials with properties tailored for chemical and biological defense needs. Ongoing research is addressing the destruction of munitions and the catalytic oxidation and hydrolysis of chemical agents and toxins, as well as techniques for detecting trace amounts of chemical hazards. The Army has consolidated its efforts in the area of highly branched dendritic molecules and will lead the services in that area. Research on hydrogen, methanol, and liquid hydrocarbon fuel cells continues as a growth area under Army leadership. The Navy continues its leadership role in novel solid-state power sources and energy transfer media. Advances in these areas are expected to contribute to

eventual development of small- to large-scale energy conversion systems. The Navy leads work in development of carbon nanotube and organic composites for electronic and structural material applications. Activities related to low-cost and novel electronic and optical components are also being pursued.

The Navy also maintains a strong program in environmental chemistry. The Air Force continues to develop novel materials synthesis methods. In particular, research in inorganic polymers holds promise of a new class of versatile materials that operate in extreme environments. The Air Force continues its leadership role in the analysis, detection, and prevention of aircraft corrosion and environmentally compliant protection systems. The Air Force is also actively pursuing approaches to develop lightweight chemical laser systems and polynitrogen propellants. Common efforts within the SPG in chemical synthesis address energetic materials, supramolecular chemistry for biomimetics and detection, and optical materials. Research on optical polymers for information processing applications is continuing to make great progress important to meeting many DoD needs. Work in tribochemistry has given researchers a fundamental understanding of the role of surface structure and chemistry in friction and wear. Current research emphasizes friction at very small scales and under extreme conditions.

Service-specific interests and commonality in Chemistry are presented in Table V–3.

**Table V–3. Service-Specific Interests and Commonality in Chemistry**

Subarea	Army (A)	Navy (N)	Air Force (AF)
<b>Materials Chemistry</b> Theory Molecular Design Synthesis and Properties of Compounds	Catalysts (chemical and biological warfare) Elastomers Reactive polymers Barrier/permeable polymers Dendritic molecules	Nano/molecular electronic materials Multifunction materials Electroactive materials Maritime coatings Nanotubes/organic composites	Inorganic-based protective coatings and space materials Aircraft coatings Polymeric high-temperature materials
	<b>Areas of Common Interest:</b> Nanostructures (A, AF); energetic materials (A, AF); power sources (A, N, AF); functional polymers (A, N, AF); sensors (A, N, AF); lubricants (N, AF)		
<b>Chemical Processes</b> Atomic and Molecular Energy Transfer Transport Phenomena Reactions Changes of State	Decon/demil chemistry CBW detection Organized assemblies Diffusion/transport in polymers Energetic ignition/detonation	Combustion/conflagration in fuels Environmental chemistry Surface and interface processes Self-assembled mesostructures energy transport	Chemical lasers Atmospheric and space signatures and backgrounds Processing (ceramics, polymers, sol gels) Thin-film growth
	<b>Areas of Common Interest:</b> Chemical dynamics (A, N, AF); tribochemistry (A, N, AF); sensors (A, N, AF); chemistry of corrosion and degradation (A, N, AF); power sources (A, N, AF)		

## D. COGNITIVE AND NEURAL SCIENCE

The DoD-wide program of research in Cognitive and Neural Science develops the science base that enables the optimization of the services' personnel resources. Areas of application include testing, training, and simulation technologies; display support for target recognition and decisionmaking; techniques to sustain human performance; human factors; and team/organizational design and evaluation methodologies. Joint agreements in 6.2 and 6.3 programs apply to manpower, personnel, and training issues. The defense-wide SPG in Cognitive and Neural Science has been responsive in aligning basic research programs in those areas.

DoD basic research activities in Cognitive and Neural Science involve two subareas: human performance and reverse engineering.

## **1. Human Performance**

Research in human performance influences the services' approach to personnel selection, assignment, and training. It also explores ways to augment personnel performance in military environments and to develop new ways of organizing better, more effective teams and command and control organizations.

In research on teams and organizations, the Army concentrates on group-leader processes, the Navy on coordination in distributed groups and models for evaluating organizational design, and the Air Force on communication strategies and interfaces important to maintaining situational awareness. In the areas of cognition, learning, and memory, the Army concentrates on training principles that underlie acquisition, retention, and transfer of soldier skills. The Navy emphasis is on artificial intelligence and AI-based models of cognitive architecture. The Air Force focus is on sensory integration, performance in synthetic task environments for command and control, and information fusion for decisionmaking support.

In stress and performance research, the Army focuses on performance issues, while the Air Force focuses on the circadian timing system underlying fatigue, performance, and the change from sleep to arousal. The Army vision and audition program seeks to optimize the user interface in visual control of vehicles and reduce the effects of intense sound. Navy research focuses on teleoperated undersea requirements, automatic target recognition for precision strike missions, and auditory pattern recognition for sonar signal analysis. More generic principles of human image communication and sound localization are being investigated by the Air Force.

## **2. Reverse Engineering**

The reverse engineering subarea exploits the unique designs of biological neural systems by discovering novel information processing architectures and algorithms potentially implementable in engineered systems. These efforts seek to imbue machine systems with capabilities for sensing, pattern recognition, learning, locomotion, manual dexterity, and adaptive control that approximate human functionality. The current Navy program in reverse engineering combines neurosciences and computational modeling in five topical areas: vision, touch/manipulation, locomotion, acoustics/biosonar, and learning. The Air Force examines biological sensor system specificity and sensitivity to provide, for example, new technologies for ambient-temperature, lightweight, low-cost infrared sensors by examining the mechanisms used by animals to detect IR signals.

Service-specific interests and commonality in Cognitive and Neural Science are presented in Table V-4.

**Table V–4. Service-Specific Interests and Commonality in Cognitive and Neural Science**

Subarea	Army (A)	Navy (N)	Air Force (AF)
<b>Human Performance</b> Personnel Selection Training Human-System Integration Teams and Organizations	Leadership Societal linkages	Tactile information processing Sensory-guided motor control	Chronobiology Neuropharmacology Synthetic task environments
<b>Areas of Common Interest:</b> teams and organizations (A, N, AF); cognition, learning, and memory (A, N, AF); stress and performance (A, AF); auditory and visual perception (A, N, AF)			
<b>Reverse Engineering</b> Machine Vision Autonomous Vehicles Automatic Target Recognition Telerobotics	None	Autonomous undersea vehicle/manipulators Neural computation plasticity Automatic sonar classification	3D audio displays Infrared biosensors
<b>Areas of Common Interest:</b> machine vision (N, AF)			

## E. ELECTRONICS

Electronics is considered a dominant force multiplier in DoD systems. Basic research in Electronics supports all elements of the *Joint Warfighting Science and Technology Plan* (JWSTP) (Reference 2) and is both need and opportunity driven. The Electronics SPG plans and conducts a forward-looking, well-integrated research program that addresses many of the currently defined mission deficiencies and operational requirements, including aiming and position accuracy of weapons, all-weather surveillance and mobility, unmanned robotic vehicles and aircraft, real-time global surveillance, and reliable (minimum downtime) global and mobile wireless communications as needed for information dominance and network-centric warfare. These requirements are driven by affordability and a continuing need for operational superiority. Affordability includes the influence of size, weight, and power on the overall cost. Operational superiority requires systems with higher accuracy and vastly greater information throughput capacity to influence real-time situation assessment, or systems performing autonomously over land, at sea, or in the air or space.

The Basic Research Program in Electronics has established a national leadership position and has initiated, advanced, exploited, and leveraged research results in many fields that impact technologies of military importance. Representative examples are research efforts on infrared detectors and lasers for both tactical and strategic applications; wide-bandgap semiconductor research that is critical for high-temperature engine controls, high-power RF active aperture arrays, and shipboard switching devices; 100-GHz logic for digital RF and beamsteering; RF and optical computing devices needed to achieve major weight/size reductions in air and spacecraft signal processors; and mobile wireless communications and networking for the highly dynamic network topologies of the battlespace. DoD basic research in Electronics is distributed over the services in a manner that avoids duplication and maximizes benefits to specific service mission requirements. Army research areas are closely coupled to Army mission requirements for ground vehicles and soldier support; Navy programs are driven by considerations derived from multifunctional RF, ocean, and submarine operational needs; Air Force research efforts are dictated by requirements for high-performance aircraft and space platforms. In addition to service-specific programs, the Electronics SPG plans for multiservice and multidisciplinary efforts to more effectively focus resources on recognized high-priority DoD topics.

The DoD Basic Research Program in Electronics is divided into three subareas: solid-state and optical electronics, information electronics, and electromagnetics.

### **1. Solid-State and Optical Electronics**

Research in solid-state and optical electronics will provide the warfighter with novel or improved electronic and optical hardware, including nanoelectronics for surveillance, target acquisition, tracking, electronic controls, radar and communication, displays, data processors, and advanced computers. Research in solid-state electronics emphasizes topics of limited commercial interest such as radiation-hardened, low-power, low-voltage applications for soldier or space support; ultra-high-frequency devices to be applied in secure communication; remote detection devices for personnel and chemical or biological agents; versatile, wideband, multifunctional RF technology; or robust building blocks for future generations of efficient, ultrafast, dedicated supercomputers. Optical electronics, including photonics, takes advantage of the very high transmission bandwidth and aims at massive optical storage and parallel channels as critical building blocks of photonic computation. Other optical research is directed to multifunction infrared (IR) and ultraviolet (UV) devices for target and threat detection and avoidance.

### **2. Information Electronics**

Basic research in information electronics will push the performance envelope for wireless communications and decisionmaking by advancing mobile wireless networking, simulation and modeling, coding, digital signal processing, and image/target analysis and recognition. Research in information electronics is dedicated to signal processing for wireless applications and image recognition and analysis. Coding schemes for secure communication and robust communication networks are being investigated. Unique cellular arrays are being investigated for image processing to bypass software and algorithm bottlenecks. Optimum control of distributed information processing and transmission is also receiving substantial attention. Innovative approaches to modeling and simulation of devices and circuits are being pursued. Modeling and sensor fusion, as well as control and adaptive arrays, are also being emphasized.

### **3. Electromagnetics**

Progress in electromagnetics will advance DoD capabilities in signal transmission and reception such as found in radar, high-power microwaves, or secure communications in built-up areas. The electromagnetics research program is focused on fundamentals of antenna design, dispersion-free beamsteering, scattering and transmission of electromagnetic (EM) signals, vacuum electronics modeling and simulation, and efficient and low-energy RF components for use predominantly in multifunctional and wireless applications. Computational electromagnetics is receiving strong emphasis, along with novel approaches to time-domain modeling of electromagnetic wave generation, transmission, and propagation. A substantial part of the program is focused on modeling of millimeter-wave phenomena by optical means. New adaptive, reconfigurable RF radio/sensor concepts are also being explored.

Service-specific interests and commonality in Electronics are presented in Table V–5.

**Table V–5. Service-Specific Interests and Commonality in Electronics**

Subarea	Army (A)	Navy (N)	Air Force (AF)
<b>Solid-State and Optical Electronics</b> Detectors Lasers Semiconductors Nonlinear Circuits	IR and UV detectors Power switches Terahertz electronics Low-power and low-voltage analog electronics	Wide-gap semiconductors Magnetic thin films All-digital RF electronics Magneto-electronics 6.1-angstrom materials	Radiation-hard electronics Nonlinear optical materials High-temperature electronics
<b>Areas of Common Interest:</b> lithography (A, N); quantum transport (A, N); nanoscale and mesoscale electronics (A, N, AF); heterostructures (A, N, AF); multifunctional devices and micro-optics (A, N, AF); device reliability (N, AF); superconductors (N, AF); IR detector materials and IR lasers, (N, A); hyperspectral imaging (A, N, AF)			
<b>Information Electronics</b> Modeling and Simulation Communications Processing and Data Fusion	Mobile, wireless multimedia distributed communications IR target recognition and image analysis Energy-efficient digital signal processing	Neural net circuits	None
<b>Areas of Common Interest:</b> modeling/simulation of circuits, devices, and networks (A, N); sensor fusion (A, N, AF); digital signal processing (A, N, AF); target acquisition (A, AF); adaptive array processing (A, N, AF)			
<b>Electromagnetics</b> Antennas Transient Sensing Tubes	Wireless and radar propagation Advanced millimeter wave (MMW) circuit and antenna integration Mobile tactical wireless and printed antennas	Dispersion-free beamsteering	Transient electromagnetics Secure propagation Distributed aperture radar
<b>Areas of Common Interest:</b> integrated transmission lines (A, N, AF); EM numerical techniques (A, N, AF); discontinuities in circuits (A, N, AF); EM scattering (N, AF); vacuum electronics (N, AF); optical control of array antennas (A, N, AF); power-efficient RF components (A, N, AF); adaptive arrays (A, N, AF)			

## F. MATERIALS SCIENCE

Advanced materials research being conducted as part of the DoD Basic Research Program includes both need-driven and opportunity-driven elements that will impact virtually all DoD mission areas in the future. The Materials Science SPG plans and conducts an aggressive, integrated research program that is leading to new classes of materials possessing, increased strength and toughness, lighter weight, greater resistance to combinations of severe chemical and complex loading environments, and improved optical, magnetic, and electrical properties. These advances are focused on meeting the transformational warfighting needs by providing access to higher performance and superior weapon systems together with improved readiness, decreased need for logistic support, increased reliability, and lower lifetime cost.

Navy programs are driven by operational considerations such as ocean surface and sub-surface vehicle designs as well as naval air, space, and missile system parameters. Air Force research efforts are dictated by requirements for high-performance aircraft and space platforms. Army research areas are closely coupled to Army mission requirements for armor/antiarmor systems, advanced rotorcraft, ground vehicles, missiles, and projectiles. In certain areas of materials research, more than one service has a vested interest in supporting programs. These areas of

commonality involve large, diverse, and long-term multidisciplinary efforts. Such efforts are jointly planned through the Materials Science SPG to maximize return on investment. For example, the area of tribology has the potential to impact the operational service life of guns, engines, and aircraft (among many other military systems). The tribology programs were planned with the Army sponsoring work on ion beam engineering/surface modification, the Navy supporting computational and experimental approaches for understanding wear surfaces and interfaces, and the Air Force focusing on failure diagnostics for aging aircraft.

The DoD Basic Research Program in Materials Science includes two subareas: structural materials and functional materials. Research in both subareas includes elements of synthesis, processing, structure, properties, theory, and modeling.

## **1. Structural Materials**

Research in structural materials is needed to satisfy operational requirements of DoD systems such as armor and penetrators; durable, high-temperature components of high-performance engines used in hypersonic air vehicles, and high-performance, low-cost spacecraft materials; and lightweight, tough, corrosion-resistant hulls of naval ships. Structural materials of principal interest are metallic materials, ceramics, composites, and polymers. The structural aspects pertain primarily to service under mechanical loads. Research is focused on designing and processing advanced materials to achieve higher performance and improved reliability at lower costs, developing new materials with unique microstructures, providing improved understanding of material behavior under a variety of complex loading and environmental conditions, optimizing interface chemistry and mechanics, and developing innovative nondestructive techniques for characterizing materials and investigating the interrelationships that couple material processing and performance. Some of the research areas of growing importance pertinent to these thrusts include computational design, aging systems, biomimetics, blast protection, and nanoscience. The area of aging systems is of particular concern for all three services in that research results may provide new opportunities for affordably maintaining and upgrading aging assets. Each of the services is investing in multidisciplinary research focused on meeting this long-term need. Research is focused in the areas of corrosion and degradation, failure mechanisms, and life prediction and life management, with each service concentrating on the special materials and structural aspects of its unique platforms and collaborating in more generic areas.

## **2. Functional Materials**

DoD systems that are affected by research in functional materials include a host of electronic devices and components; mobile and fixed electro-optical communication equipment; radars, sonars, and other detection devices; displays; readers; and power-control devices. Research in this area is focused on understanding and controlling materials processes to achieve affordable products and reliable performance, attaining materials-by-design capability to provide new materials with unique properties, investigating the principles of defect engineering, and exploring the potential of nanoscience. For example, in the area of smart systems, novel material approaches that include very high strain single-crystal piezoelectrics ( $\text{PbMgNbO}_3\text{--PbTiO}_3$ ) and magnetic materials ( $\text{Ni}_2\text{MnGa}$ ) are being pursued. These materials offer new opportunities for dynamic control of structures in advanced aircraft, rotorcraft, ships, and submarines. Further, such materials will enable the development of very sensitive devices for perimeter sensing, sonar systems, and mine detection. Areas of growing importance include nanoscience, smart systems, and thermoelectrics. For example, in the area of thermoelectrics, novel material approaches that include

lead telluride (PbTe)-based superlattices, skutterudites, and organic composites are being pursued. These materials offer new opportunities for low-temperature cooling of night-vision equipment and electronics, and for high-temperature applications for shipboard cooling and power generation.

Service-specific interests and commonality in Materials Science are presented in Table V-6.

**Table V-6. Service-Specific Interests and Commonality in Materials Science**

Subarea	Army (A)	Navy (N)	Air Force (AF)
<b>Structural Materials</b> Synthesis Processing Theory Properties Characterization Modeling	Manufacturing science (land/rotorcraft systems, armaments) Armor/antiarmor materials Diesel engine materials Gun tube liner materials	Marine corrosion, oxidation, and fatigue Advanced materials for ships and submarines Acoustically damped structures Multifunctional designed materials	High-temperature fatigue and fracture Air and spacecraft engine and structural materials Aging aircraft Functionally graded materials Materials processing Modeling and simulation of materials in engineering design
<b>Areas of Common Interest:</b> advanced composites (A, N, AF); adhesion/joining (A, N, AF); tribology (A, N, AF); ceramics (A, N, AF); intermetallics (N, AF)			
<b>Functional Materials</b> Synthesis Processing Theory Properties Characterization Modeling	Defect engineering Optical components IR detector materials CBD materials Smart materials	Ferrite films Ferroelectrics Dielectrics for passive components Acoustics/active materials Superconductivity	(Topics addressed under Chemistry (Section C), Electronics (Section E), Mechanics (Section H), and Physics (Section I) basic research areas)
<b>Areas of Common Interest:</b> optoelectronics (A, N); magnetic materials (A, N)			

## G. MATHEMATICS AND COMPUTER SCIENCES

Mathematics provides the analytical and computational methods for the biological sciences, information science, life science, operations research, and the physical sciences. New methods have become increasingly important for the understanding of multiple-scale, nonlinear, strongly interactive, dynamical systems in materials, photonics, sensor fusion, nanotechnology, and network security, to name a few. Computer science provides the methodologies to implement the nonlinear mathematics into intelligent software agents, battlefield decision aids, computer vision, and the processing of heterogeneous and distributed databases.

The scaling behavior of complex systems for modeling and simulation—together with considerations of realism, interoperability, and synchronization—are vital for military needs. The design of intelligent agents, the foundations of heterogeneous and distributed databases, and the design and evolution of software systems and real-time algorithmic and architectural issues for battlefield decision aids are all important areas of DoD interest that involve mathematics and computer science in critical ways.

The Army, Navy and Air Force support basic research in mathematics on nonlinear dynamics, complexity/computation theory, and multiple-scale phenomena. The results of such research are applicable to the specific concerns of the individual services, as well as to common

issues. The Army leads in mathematics research pertinent to the development and performance of novel materials for advanced armor and antiarmor systems; the Navy leads in ocean modeling and wavelet-based image processing; the Air Force leads in control and guidance.

Adaptive methods constitute a significant part of the computational mathematics research activity, with less emphasis on traditional linear filtering and more development in the area of nonlinear filtering. Operations research is one of the DoD drivers of mathematical programming and the modeling of discrete-event systems—indicative of the need for improved algorithms for large, complex planning problems and logistics in each of the services. The Army has the lead in probabilistic methods for automatic/aided target recognition; the Air Force is strongest in the modeling of compressible and hypersonic flow; the Navy is ahead in the computation of incompressible flows for hydrodynamic design.

The different research emphases of the services are a consequence of the distinct requirements associated with their various platforms. These research needs are the basis of the topical computer science areas pursued within each service. For instance, while the Navy develops novel computing concepts with potential to assist the fleet in accomplishing its missions dependably, the Army is driven by requirements pertinent to the development of the digital battlefield. The Air Force also has unique requirements because of demanding real-time computing-speed for aerospace defense. In the area of intelligent systems, each of the services' research offices has considerable interest and activity. On the other hand, the virtual environments subarea is being pursued primarily by the Army (Institute of Creative Technology) to support a variety of combat simulation needs and battlespace management applications. Machine vision is being pursued by all services to support reconnaissance and surveillance missions. However, the focus of this research differs significantly from service to service due to the widely different physical contexts in which they operate (land, open ocean and littoral zones, the atmosphere, and space).

## **1. Mathematics**

Within the DoD Basic Research Program, research in mathematics falls into three general subareas: modeling and mathematical analysis, computational mathematics, and stochastic analysis and operations research.

### ***a. Modeling and Mathematical Analysis***

The fundamental knowledge derived from experiments in the physical, biological, and life sciences is encapsulated in the language of mathematical modeling and analysis. This knowledge increases DoD's ability to develop advanced ground vehicles, aircraft, and naval vessels, and to identify their failure modes along with those of delivery systems, radar, sonar, sensors and actuators, and other military equipment.

### ***b. Computational Mathematics***

The predictive ability of any set of constitutive equations depends on the ability to reliably increment those equations forward in time. Thus, computational mathematics impacts DoD's capabilities in ballistics, target penetration, vulnerability of ground vehicles, aircraft and naval vessels, as well as combustion, detonation, and stealth technology.

### ***c. Stochastic Analysis and Operations Research***

The systematic treatment of error, uncertainty, and chance is fundamental in the control and prediction of complex systems. Research in this area impacts DoD capability in design,

testing, and evaluation of systems; making decisions under conditions of uncertainty; and logistics and resource management.

## 2. Computer Sciences

Within the DoD Basic Research Program, research in the computer sciences falls into three general subareas: intelligent systems, software, and architecture and systems.

### a. Intelligent Systems

Research in intelligent systems focuses on the control of complex dynamical phenomena, particularly in engineering systems. The understanding and control of intelligent systems directly affects DoD capabilities in automated command, control, communications, and intelligence (C<sup>3</sup>I) systems, guidance and control of semiautomated and automated platforms, automatic target recognition, and real-time warfare management decision aids.

### b. Software

Research in software addresses the perceived engineering technology needs of the future and defines the DoD critical-path open-research issues to be resolved. This research influences DoD capabilities in automation, decision support, combat systems, warfare management systems, distributed interactive simulation, digitization of the battlefield, training, and man-machine interaction.

### c. Architecture and Systems

This broad area of research into the use of hybrid system architectures and advanced distributed simulation affects DoD capabilities in warfare management, real-time data acquisition, training, C<sup>3</sup>I, geographic information systems, automatic target recognition, system automation, distributed interactive simulation, and vulnerability and lethality analysis.

Service-specific interests and commonality in Mathematics and Computer Science are presented in Table V-7.

**Table V-7. Service-Specific Interests and Commonality in Mathematics and Computer Science**

Subarea	Army (A)	Navy (N)	Air Force (AF)
<b>Mathematics</b>			
<b>Modeling and Mathematical Analysis</b> Physical Modeling and Analysis	Mathematics of materials science Reactive flows	Ocean modeling and mixing	Control and guidance Nonlinear optics
	<b>Areas of Common Interest:</b> invest problems (N, AF); multiscale phenomena (A, N, AF); nonlinear dynamics (A, N, AF)		
<b>Computational Mathematics</b> Numerical Analysis Discrete Mathematics	Computational mechanics Data representation Discrete mathematics	Computational acoustics Computational statistics Computational logic	Computational control Compressible and hypersonic flow
	<b>Areas of Common Interest:</b> adaptive methods (A, N, AF); computational electromagnetics (N, AF)		

**Table V–7. Service-Specific Interests and Commonality in Mathematics and Computer Science (continued)**

Subarea	Army (A)	Navy (N)	Air Force (AF)
Mathematics (continued)			
Stochastic Analysis and Operations Research Statistical Methods Applied Probability Optimization	Statistical modeling Simulation methodology Nonlinear filtering	Random fields	Hybrid systems Combinatorial search
	Areas of Common Interest: stochastic image analysis (A, N); stochastic partial differential equations (A, N); mathematical programming (A, N, AF); network and graph theory (A, N, AF); nonlinear filtering (A, N)		
Computer Science			
Intelligent Systems Control Learning Natural Language Processing Motion Planning Virtual Environments Languages	Intelligent control Natural language processing Machine intelligence	Case-based reasoning Machine learning Motion planning	Intelligent real-time problem solving Intelligent tutoring Intelligent agents
	Areas of Common Interest: data fusion (A, AF); machine vision (A, N, AF), virtual environments (A, N); novel computing paradigms (A, N, AF)		
Software Software Engineering Software Environments Languages	Heterogeneous database Formal languages Automation of software development	Hard real-time computing Structural complexity Programming logic	Information warfare high-performance knowledge bases
	Areas of Common Interest: software environments (A, N, AF); programming languages (A, N, AF); formal design and verification (N, AF)		
Architecture and Systems Compilers Operating Systems	Scalable parallel combat models Hybrid system architectures	Ultradependable multicomputing systems Secure computing	Distributed computing for C <sup>3</sup>
	Areas of Common Interest: operating systems (A, N, AF); man-machine interface (A, N)		

## H. MECHANICS

DoD is the principal source of sponsorship for basic research in Mechanics. The overall scientific goal is to understand and control the mechanical behavior of military systems, including combat vehicles and weapons. Such understanding leads to revolutionary system-level improvements in performance, survivability, and costs. Research efforts will result in not only the benefits cited above, but also in advances in analytical design and testing methods, including modeling and simulation tools and diagnostic instrumentation.

Mechanics, as an engineering science, is closely tied to the issue of complexity. Complexity manifests itself in several ways, such as the extremely large range of scales present in a phenomenon, the plethora of simultaneous interactions that govern its dynamics, and the mathematical nonlinearity and anisotropy in the descriptive mathematical models. Research in mechanics is focusing on understanding (1) relationships between microscale phenomena and macro-scale response and (2) submicroscale mechanical response devices for micro- and nanotechnology and for obtaining service-history data. Research also seeks to (1) invent new concepts for predicting and controlling strongly nonlinear/dynamic phenomena; (2) conduct multidisciplinary research among the different disciplines of mechanics and with complementary capabilities in

physics, chemistry, biology, and mathematics; and (3) create novel simulation and diagnostics tools at an appropriate level of complexity relevant to engineering. These characteristics, alone or in combination, are present in all DoD research in mechanics.

Mechanics research supported by the DoD Basic Research Program is divided into three general subareas: solid and structural mechanics, fluid dynamics, and propulsion and energy conversion. Each service performs research responsive to its particular system drivers. In a number of areas, the services have common interests. In general, each service performs research in an area of commonality, with specific nonoverlapping technology targets. For example, in structural dynamics and smart structures, the Army emphasizes stability and control of rotorcraft structures, the Navy focuses on underwater explosion effects and structural acoustics, and the Air Force targets fixed-wing aeroelasticity and engine dynamics.

## **1. Solid and Structural Mechanics**

Research in this area deals with the identification, understanding, prediction, and control of multiscale phenomena that affect the performance and reliability of modern DoD structures. The research includes (1) structures that range in size from those on nano- and microscales to large space/air/sea/land platforms; (2) structures that are made from metals, ceramics, polymers, composites, and functionally graded materials; (3) structures that are intended to perform multiple tasks, are subjected to various combined loadings, and contain various “smart” or active materials; and (4) aeroelastic structures that operate in a range of Mach numbers from low subsonic to hypersonic. The anticipated outcomes of research are physics-based models for response prediction, an enhanced understanding of unsteady behavior, and robust active control leading to integrated optimal designs of materials, structures, and, in some cases, flow control. Emphasis is in integrating knowledge from the micro to the macro level and on macro-optimization. The phenomena range from fracture and fatigue initiated at micromechanical levels to multiple-scale interactions that need to be quantified in order to optimize the dynamics of complex structures. The issues of life prediction/extension of engineered structures are approached by relying on the disciplines of solid mechanics of finite deformation and failure, penetration mechanics, and computational mechanics. Research on “smart” structures integrates actuators, sensors, and control systems into the structure to accomplish damage control, vibration reduction, noise reduction, and reconfigurable shapes. Opportunities exist for optimizing lift-to-drag ratio, increasing lift, expanding the flight envelope, and reducing required installed power on DoD aerospace vehicles. Reliability of ship structures, underwater explosion effects, structural acoustics and dynamics, shock isolation/vibration reduction in machinery, and noise control are addressed. A growing area of interest is the micromechanics of devices that are used for power distribution, maneuvering, and structural health monitoring. In many cases throughout this research, emphasis is placed on nonlinear phenomena, multifunctional applications, and quantifying the uncertainty inherent in all modeling.

## **2. Fluid Dynamics**

The design, performance, and stealth of DoD weapons, platforms, and subsystems depend on tailoring the distributed fluid mechanical loads that control their dynamics. Modern supercomputers, whole-field laser diagnostics, sophisticated turbulence models, and microelectromechanical actuators are used, alone or in combination, to produce validated prediction/control methods. Central to fluid dynamics research is the understanding, prediction, and control of turbulent flows with high Reynolds numbers. Such flows can be rotorcraft wakes, unsteady flows

around maneuvering fighters, or multiphase flows around marine propulsors. Increased attention is being given to the understanding of compressibility, aero-optic disturbances caused by turbulence, and full-scale Reynolds number effects in aerodynamics and hydrodynamics. Simulations of high-speed flows in complex configurations relevant to hypersonic vehicles are being pursued, with emphasis on integrated approaches to inlets, supersonic combustion, and nozzles. Interdisciplinary research explores intelligent flow control strategies using microelectromechanical systems (MEMS) for thrust vectoring, high lift, drag reduction, and noise/signature reduction. An important new focus involves simulations of free-surface/two-phase flows around surface ships, including wave breaking and bubble generation/transport, and submerged wakes in a sheared, stratified, and turbulent environment.

### **3. Propulsion and Energy Conversion**

Research in this area is crucial to the performance, stealth, reliability, affordability, and maintainability of DoD weapons or platforms. The research is inherently and strongly multidisciplinary, combining knowledge from chemical kinetics, multiphase turbulent reacting flows, thermodynamics, detonations, plasmas, and control. Increasing emphasis is being given to active sensing, actuation, and control for engines, including integration into an intelligent engine model; high-pressure kinetics; and combustion diagnostics. Another research focus involves synthesizing new energetic materials/fuels, characterizing their behavior, and controlling their energy release rates for specific DoD weapon applications in coordination with the Chemistry SPG. Research on the physical, chemical, and material interactions in solid propellants at realistic pressure environments addresses their combustion mechanisms. Active combustion control is being pursued for tailoring tactical missile motor behavior and compact shipboard incinerators. High-performance aircraft require engines with high operating temperature and pressure. Research to achieve more efficient and durable combustion dynamics and to utilize high-thermal-capability fuels at supercritical thermodynamic states is being conducted. High-speed propulsion and access to space are areas of renewed emphasis to contribute to the National Aerospace Initiative.

Service-specific interests and commonality in Mechanics are presented in Table V–8.

**Table V–8. Service-Specific Interests and Commonality in Mechanics**

Subarea	Army (A)	Navy (N)	Air Force (AF)
<b>Solid and Structural Mechanics</b> Structural Dynamics Composites Aeroelasticity Acoustics	Inelastic mechanisms Dynamic fracture of heterogeneous structures Impact, penetration, and shock	Structural acoustics Thick composites Micromechanics of electronic devices and solids	Nonlinear aeroelasticity Mechanics of high-temperature materials Stable space structures
	<b>Areas of Common Interest:</b> structural dynamics and control (A, N, AF); damage and failure mechanics/quantitative nondestructive evaluation (A, N, AF); smart structures (A, N, AF); mechanics of multifunction materials (A, N, AF); multiscale modeling (A, N, AF)		
<b>Fluid Dynamics</b> Aerodynamics Hydromechanics	Rotorcraft aerodynamics Projectile aeroballistics Micro/mesoscale devices	Free-surface phenomena Hydrodynamic wakes Hydroelasticity and hydroacoustics	Turbomachinery, fixed wing, and hypersonic aerothermodynamics Aero-optics Plasma and magnetohydrodynamics flow control
	<b>Areas of Common Interest:</b> turbulence (A, N, AF); flow control (A, N, AF)		
<b>Propulsion and Energy Conversion</b> Air-Breathing Systems Rockets Explosives	Reciprocating engines Gun propulsion Small gas turbines	Underwater propulsion Missile propulsion Explosives	Large gas turbines Supersonic combustion Access to space Spacecraft propulsion
	<b>Areas of Common Interest:</b> high-energy materials formulation, combustion, and hazards (A, N); soot formation (A, N); turbulent combustion (A, N, AF); spray combustion (A, AF)		

## I. PHYSICS

Physics is the scientific discipline devoted to discovering and employing the fundamental principles that underlie the laws of nature. Physics research investigates novel phenomena, formulates and tests new concepts and theories, develops new experimental tools and techniques, performs new measurements, develops new computational techniques, and applies all of the above to developing useful devices and novel or improved materials. DoD physics research has the goal of transitioning scientific progress and breakthroughs into enhanced DoD capabilities. These materials and devices have the potential to extend and enhance the operational capabilities of many different types of military equipment and systems in the areas of weapons, weapon platforms, sensors, communications, navigation, surveillance, countermeasures, and information processing. As such, the Physics SPG crosses all four elements of the *Joint Warfighting Science and Technology Plan* (Reference 2) by supporting S&T contributions to military needs. These contributions include ground, sea, air, and space sensor research; quantum information science research for greatly enhanced computational capabilities; ultra-secure communications and sensor improvement research; guidance and control; lethality technologies; high-power microwaves for nonlethal weapons; atomic and optical clocks for GPS performance improvements; deployable unattended sensors; and techniques for detecting and evaluating the existence of manufacturing capabilities for weapons of mass destruction.

The definition of service-specific research in physics clearly follows lines of respective mission applications. The Army focuses on soldier and land platforms with a strong emphasis on smaller, lighter, more lethal, and more survivable platforms; the Navy on surface ships, including

carriers and their aircraft, and submarines; and the Air Force on atmospheric and space flight applications. The Air Force has an active program in optical compensation for the imaging of space objects through the atmosphere. Additionally, the need for lightweight, small devices for airborne platforms has resulted in an Air Force program to develop visible laser technology for possible use in optical countermeasures. The Army has an active program in compact displays and detectors to support the combat soldier, in addition to programs for sensor protection from laser radiation for all sensors, including soldiers. The Army also has a program to significantly improve target detection and identification capabilities, especially under highly cluttered or obscured conditions, by developing ultra-sensitive atom optics-based detectors, and by advancing unconventional optics techniques such as integrated computational imaging. The Navy pursues research to develop compact ultra-precise atom gyroscopes for GPS-like undersea navigation and guidance. Naval research in acoustics is focused on physical acoustics and underwater acoustics involving propagation and transducers. Application of nonlinear dynamics to signal detection and classification is also of high naval interest.

DoD Physics research falls into three general subareas: energy production and electromagnetic radiation, matter and materials, and sensing and detection.

## **1. Energy Production and Electromagnetic Radiation**

This area of research focuses on power generation for various applications and sources of electromagnetic radiation—from radio waves to gamma rays. Advanced radiation sources are needed to satisfy DoD requirements, including those for C<sup>3</sup>I, radar, sensors, electronic warfare, and directed-energy weapons. In addition to radiation sources, this area involves the propagation of radiation in different military environments. The Air Force has the tri-service lead in directed energy and funds research that benefits all three services regarding directed-energy sources and techniques, while also performing research in optical compensation for atmospheric distortion and propagation of electromagnetic signals through the ionosphere. The Army is funding work on photonic-band engineering for illuminators that can pierce through the battlefield environment. The Navy is investigating advanced pulse power sources and ultra-high electromagnetic fields. Common research areas include tunable infrared lasers, nonlinear optics, ultra-fast electro-optics, and free-electron radiation sources.

## **2. Matter and Materials**

This area of research focuses on materials from nanoscale (single atom- or molecule-sized devices) to macroscale (bulk materials such as high T<sub>c</sub> superconductors) that impact many DoD systems. Atom optics and quantum effects are being used to develop ultrasensitive detectors, as well as unprecedented computational and communication capabilities. Neutral plasma effects can provide stealthy conditions for DoD aircraft and satellites. In addition, nanoscience research is being pursued to develop ultrasmall sensors and materials with unique properties for signature control, electronics, and armor. Specific research undertaken by the Air Force is focusing on potential uses of antiprotons and antihydrogen as lightweight, high-energy-density fuels for advanced aircraft systems, as well as high-T<sub>c</sub> superconductors to improve power budgets for air and space platforms. The Army is researching novel liquid crystal and adaptive gating-based optical limiters for battlefield sensor protection. Naval research is focused on improved atomic and optical clocks, physical acoustics for improved sonar detectors, and ultra-precise atomic gyroscopes for improvements to submarine navigation systems.

### 3. Sensing and Detection

This area of research focuses on sensing and detection of signatures and platforms for both friendly and enemy forces. The survivability of friendly and unfriendly platforms (ships, tanks, aircraft, spacecraft) and systems (e.g.,  $C^3I$ ) depends on advances in devices and phenomenology—in both the oceanographic and atmospheric arenas. Research thrusts include the scientific underpinning of optical image processing and automatic target recognition, which is applicable to the missions of all three services. The Air Force must protect space assets against energetic charged and neutral particles that can damage sensors, and is developing tools to forecast space weather storms. The Army needs to see through the dust of battle, calling for advances in detectors, optics, and imaging science, while advanced sensors require better phenomenology. Naval research on acoustic and nonacoustic underwater detection and classification of submarines and mines has employed nonlinear signal processing methods and novel stochastic resonance detectors.

Service-specific interests and commonality in Physics are presented in Table V–9.

**Table V–9. Service-Specific Interests and Commonality in Physics**

Subarea	Army (A)	Navy (N)	Air Force (AF)
<b>Energy Production and Electromagnetic Radiation</b> Sources Propagation	Photonic band engineering Atmospheric propagation of ultrashort laser pulses	X-ray sources Ultrahigh electromagnetic fields Pulse power Beam plasma dynamics	Optical compensation Microwave sources Gamma ray sources Visible lasers Ionospheric modification and propagation
	<b>Areas of Common Interest:</b> tunable IR lasers (A, N); ultrafast electro-optics (A, N, AF); novel lasers (A, N, AF); semiconductor lasers (N, AF); nonlinear optics (A, N, AF); optical diagnostics and testing (A, N, AF); coherent free-electron radiation sources (N, AF)		
<b>Matter and Materials</b> Atomic and molecular Condensed matter Plasma	Quantum information science Sensor protection	Physical acoustics Energetic and nonlinear IR materials Atomic and optical clocks Atomic gyroscopes Condensed matter structure determination Positron plasmas	Spin polarization Antiprotons and antihydrogen Dynamics of ultracold plasmas High- $T_c$ superconductors
	<b>Areas of Common Interest:</b> ferroelectrics (A, N); nanostructures (A, AF); surfaces and interfaces (A, AF); atom optics (A, N, AF); atom traps (A, N, AF); nonneutral plasmas in traps (N, AF); nonneutral plasma effects (N, AF); computational physics (A, N, AF); nonlinear control (A, N, AF)		
<b>Sensing and Detection</b> Oceanographic and Atmospheric Phenomenology and Devices	Integrated sensory science Imaging science Unconventional optics Solitonic computing	Nonlinear acoustics Sound/fluid/structure interactions Active and passive sonar Stochastic resonance detectors	Atmospheric discharges Atmospheric neutral particles impacting spacecraft Space environmental forecasts
	<b>Areas of Common Interest:</b> optical image processing (A, N, AF); nonlinear dynamics/chaos (A, N, AF); gravity gradiometers (A, N, AF)		

## **J. TERRESTRIAL AND OCEAN SCIENCES**

The DoD requirement for a core competency in Terrestrial and Ocean Sciences arises from the significant impact and, at times, controlling nature of the natural environment on DoD operations and materiel. The broad range of terrestrial and oceanic features and environmental conditions that may confront DoD around the world can constitute either a formidable barrier or a significant advantage. There is a particular need to better understand, model and simulate, and predict those conditions and environments that are most dynamic, enabling or restrictive to system performance or military operations to enhance such activities as precision engagement, dominant maneuver, and focused logistics and sustainment of strategic systems. The nature of the specific DoD applications for these research results distinguishes the details of these research areas from more general environmental research supported by other funding agencies.

### **1. Terrestrial Sciences**

DoD research in terrestrial sciences is directed toward the study of the broad spectrum of land-based phenomena that affect U.S. forces as they operate upon the Earth's surface and its ephemeral natural surface covers. Basic research in terrestrial sciences is concerned with the impact of surface, near-surface, and subsurface environments on DoD activities, and is directed at those particular elements that may have significant bearing on Army Transformation and the Objective Force. The investment in terrestrial sciences will strongly augment DoD's information operations and increase capabilities to project and sustain U.S. forces, protect bases of operation, and deny enemy sanctuary by providing realistic, focused, and optimized decision support tools. Additional issues of importance are the civil engineering aspects of DoD facilities and installations; the management and stewardship of DoD installations, particularly with regard to the sustainability of DoD training and testing; and the remediation of DoD contaminated sites.

DoD research in terrestrial sciences falls in three subareas: terrain properties and characterization, terrestrial processes and landscape dynamics, and terrestrial system modeling and model integration.

#### ***a. Terrain Properties and Characterization***

The ability to understand and utilize the variable topographic and physical characteristics of the landscape is critical to mobility/countermobility, communication, survivability, and troop and weapon effectiveness. Thus, a foundation to enhanced battlefield capability for the agile, precision-strike Objective Force will be superior knowledge of terrain and the ability to incorporate that knowledge into DoD doctrine, system development, and testing/training-to-mission planning and rehearsal, field operations, and focused logistics. Characterization of the surface geometry and features of complex terrain is needed to enhance planning and tactical decision-making and to tailor equipment to the challenges of the natural and urban environments. Both fundamental data on the distribution and character of natural and manmade features and information about the dynamic condition of the terrain are required for rapid mapping, installation support, and environmental stewardship. A major goal of this effort is rapid generation, analysis, and utilization of remotely sensed terrain data describing dynamic battlefield conditions. This force-multiplying capability will enhance a commander's ability to visualize the battlefield at multiple resolutions and execute combat operations using an efficient decisionmaking cycle much more rapidly and effectively than an adversary.

### ***b. Terrestrial Processes and Landscape Dynamics***

Enhanced understanding and numerical description of terrestrial processes affecting DoD operations are the focus of this research area. Improved measurements and theoretical treatments are needed to treat the complex, often nonlinear dynamics governing these processes, which often operate over a wide range of discontinuous scales of time and space, making them extremely difficult to characterize and quantify. Of particular research interest are those operational environments (i.e., cold region, desert, tropic, coastal, mountains, and urban) that are most restrictive to the Army. Geomorphic activity exerts a driving feedback on the hydrologic cycle. These fluid–terrain interactions and feedbacks are highly nonlinear and operate over a very broad range of spatial and temporal scales. Sensor and signature energy interaction with the dynamic terrain environment dramatically influences the performance of weapon and sensor systems, particularly those reliant on IR, acoustic, seismic, or millimeter-wave technologies. Civil engineering aspects of protective structures and sustainable design require in-depth knowledge of such diverse areas as blast effects and the impact of climate change. Critical to developing an engineering-scale understanding of the properties and behavior of surface environments is a fundamental knowledge about the processes that operate on surficial materials at a variety of scales. Field observation, laboratory experimentation, and computational modeling must be integrated to solve well-formulated problems. Predictive geotechnical models, based on well-characterized constitutive relationships, are required to identify controlling processes and parameters across a spectrum of scales.

### ***c. Terrestrial System Modeling and Model Integration***

A major objective of the effort to characterize the natural environment and study surficial processes is to develop or enhance integrated system models and simulators. The information and products arising from research will result in improved model input parameters or enhanced numerical methods, algorithms, and simulation capabilities. DoD must continually develop new features for existing numerical models and, in some instances, new environmental model systems. Three areas of particular interest are vehicle terrain interaction, dynamic terrain reasoning, and sustainable land use. The Army has an acute need to understand the influence of terrain properties and behavior on feature identification, mobility and maneuverability, and sensor interaction in the context of providing planning and rehearsal decisionmaking tools, real-time trafficability/mobility assessments, and optimized system performance. It is also necessary to understand the interrelated impacts of land-based military training and testing on terrain, hydrologic networks, geomorphic response quality, and ecosystems; and to develop integrated models that can be applied to sustainable military facility and land management, environmental quality considerations, and natural resources conservation.

## ***2. Ocean Sciences***

Ocean processes that directly affect DoD operations include tides, currents, water temperature and density, waves (surface and internal), and the distribution and concentration of the dissolved and particulate matter that affects how light and sound are transmitted through the ocean. The domain of interest is the entire theater of naval and marine operations, from coastal land areas to the central ocean gyres and from the air–ocean interface to the sea floor. The primary areas of investment are in sensors and platforms, which enable the warfighter and researcher to monitor and assess the ocean environment in new and novel ways; focused field and laboratory investigations designed to provide a better understanding of dynamic ocean processes;

and the development of accurate ocean process models that enable the user to simulate and forecast important oceanographic conditions.

***a. Sensors and Platforms***

Fundamental knowledge about the ocean arises primarily from observations, and our level of understanding can go no further than the current database of observations. It is not surprising, therefore, that continued refinements to existing sensors and development of the next generation of sensors are necessary investments for any area of oceanographic research. Once a process is understood sufficiently well that a predictive model has been developed, model accuracy is completely dependent on our ability to define the initial and boundary conditions (i.e., to make key on-scene observations at specified times and locations). This means not only having accurate, robust sensors, but also developing the platforms that will transport those sensors within the model domain. Toward this end, significant investments and advancements are being made in autonomous sampling systems, including sensors, platforms, and communications. In the view of many top-ranked oceanographers, this technology has the potential to revolutionize how we sample the ocean.

***b. Process Studies***

Many ocean processes—biological, chemical, and physical—are beyond our ability to model accurately because we lack the fundamental understanding necessary to describe them within a mathematical framework. To achieve a forecast capability, focused, multiyear, multidisciplinary investigations are conducted. These include controlled laboratory experiments and intensive field campaigns. Because field campaigns are expensive, many of them are designed to span several programs within DoD and often include collaborative efforts with other federal, state, and local funding agencies. A good example of the interagency support for field observations is the funding structure for the University National Oceanographic Laboratory System (UNOLS) fleet, jointly funded by the Department of the Navy and the National Science Foundation. Often, a field campaign will result in the documentation of a process or phenomenon that does not fit into our ideas of how the ocean works. Examples are the recent discovery of thin biological stratifications within many coastal environments, very intense solitons generated within marginal seas, and strong fluorescence signatures associated with the shallow ocean floor.

***c. Modeling and Prediction***

The ultimate goal of any oceanographic investigation is to understand the process in question so completely that with key observations a condition can be predicted at some time in the future. From the DoD perspective, this predictive capability would then be used to (1) take advantage of the natural environment to the extent possible with planning operations and (2) develop technologies that will reduce or eliminate any confounding influence on the part of the environment. To achieve this goal, an ocean process, represented as a set of observations, must be expressed in terms that a computer understands—equations embedded within algorithms. For this reason, a significant portion of the ocean science investments is directed at computational methods and resources and theoretical and applied mathematics. However, the modeling work does not stop with a believable simulation. In fact, the most difficult, time-consuming, and expensive part of developing a predictive model is the validation process—comparing predictions with observations. While the terms evoke visions of a software developer sitting at a computer terminal, much of this work requires field observations with accurate and appropriate sensors.

From this perspective, one can appreciate the close and often overlapping relationship between these three investment areas.

Service-specific interests and commonality in Terrestrial and Ocean Sciences are presented in Table V–10.

**Table V–10. Service-Specific Interests in Terrestrial and Ocean Sciences**

Subarea	Army (A)	Navy (N)	Air Force (AF)
<b>Terrestrial Sciences</b>			
<b>Terrain Properties and Characterization</b>	Terrain data generation and analysis Natural material properties Site characterization	Bathymetry and sediment composition Subsea floor morphology	None
<b>Terrain Processes and Landscape Dynamics</b>	Surficial processes and geomorphology Hydrometeorology and hydrology Coastal erosion and engineering Groundwater flow and mass transport	Resuspension and near-shore sediment transport processes Benthic bioturbation Mine burial dynamics	None
<b>Terrain System Modeling and Model Integration</b>	Tactical mobility and logistics-over-the-shore Sustainable testing and training	Sediment transport and mine burial models Resuspension and shallow-water clarity models Shallow-water acoustical propagation models	None
<b>Ocean Sciences</b>			
<b>Sensors and Platforms</b>	Optical remote sensing and IR imaging	Autonomous operations Battlespace characterization	None
<b>Process Studies</b>	Surficial hydrologic processes Coastal sediment transport	Coastal and open ocean dynamics Biological productivity Air–sea and benthic processes Optical and acoustical propagation	None
<b>Modeling and Prediction</b>	Ground water and coastal	Coupled ocean process	None

## K. DISTRIBUTION OF FUNDING AMONG THE RESEARCH AREAS

The distribution of funding among the 10 Basic Research Areas is shown in Table V–11.

**Table V–11. Basic Research Funding by Service for Each Research Area (\$millions)**

Service	FY02	FY03	FY04	Service	FY02	FY03	FY04
<b>Atmospheric and Space Sciences</b>				<b>Materials Science</b>			
Army	5.7	5.6	5.7	Army	24.0	26.0	26.0
Navy	28.4	28.3	27.1	Navy	30.8	32.8	30.5
Air Force	16.7	15.5	15.7	Air Force	16.4	15.0	15.2
<b>Total</b>	<b>50.8</b>	<b>49.4</b>	<b>48.5</b>	<b>Total</b>	<b>71.2</b>	<b>73.8</b>	<b>71.7</b>
<b>Biological Sciences</b>				<b>Mathematics and Computer Sciences</b>			
Army	25.3	25.8	37.8	Army	31.9	31.5	41.8
Navy	30.6	25.8	22.3	Navy	27.6	26.0	26.0
Air Force	13.8	14.4	14.4	Air Force	35.1	33.2	29.6
<b>Total</b>	<b>69.7</b>	<b>66.0</b>	<b>74.5</b>	<b>Total</b>	<b>94.6</b>	<b>90.7</b>	<b>97.4</b>
<b>Chemistry</b>				<b>Mechanics</b>			
Army	7.0	7.0	7.0	Army	4.5	4.5	4.5
Navy	27.4	26.4	26.0	Navy	44.1	49.0	44.5
Air Force	28.8	29.6	27.2	Air Force	21.4	22.5	22.7
<b>Total</b>	<b>63.2</b>	<b>63.0</b>	<b>60.2</b>	<b>Total</b>	<b>70.0</b>	<b>76.0</b>	<b>71.7</b>
<b>Cognitive and Neural Science</b>				<b>Physics</b>			
Army	11.4	12.1	12.0	Army	12.4	13.9	13.9
Navy	23.3	19.7	16.6	Navy	38.2	40.8	39.1
Air Force	12.9	13.0	12.8	Air Force	24.1	22.8	22.8
<b>Total</b>	<b>47.6</b>	<b>44.8</b>	<b>41.4</b>	<b>Total</b>	<b>74.7</b>	<b>77.5</b>	<b>75.8</b>
<b>Electronics</b>				<b>Terrestrial and Ocean Sciences</b>			
Army	23.5	23.7	23.4	Army	5.0	5.0	5.0
Navy	37.8	57.3	55.7	Navy	106.6	106.2	98.1
Air Force	27.5	24.6	23.9	Air Force	0.0	0.0	0.0
<b>Total</b>	<b>88.8</b>	<b>105.6</b>	<b>103.0</b>	<b>Total</b>	<b>111.6</b>	<b>111.2</b>	<b>103.1</b>

## CHAPTER IV

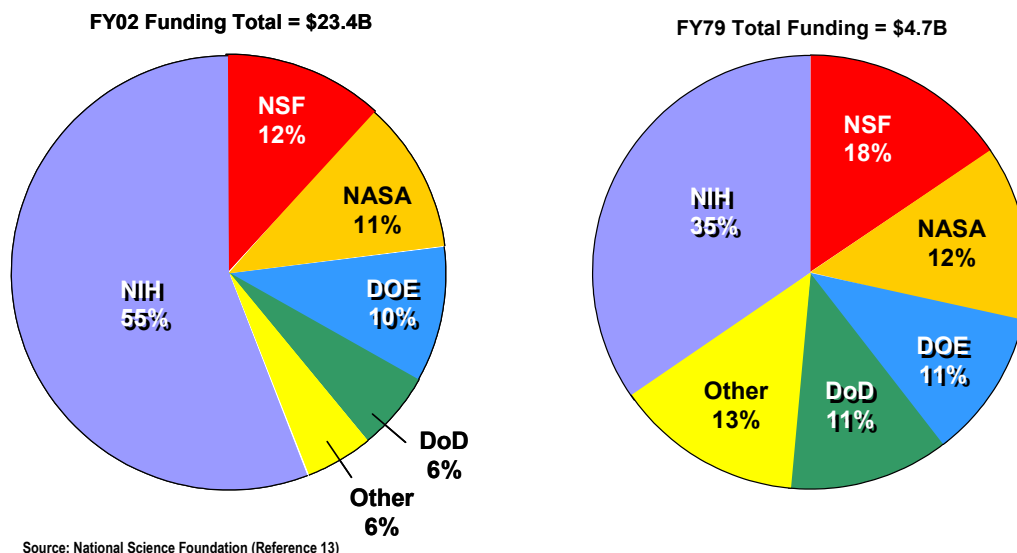
### DEFENSE BASIC RESEARCH FUNDING

#### A. FUNDING COMPARISONS

##### 1. DoD and Other Federal Basic Research Funding

To place the funding of defense basic research in the proper context, it is useful to compare the funding levels of DoD basic research with those of other federal agencies. The basic research funding among federal agencies for FY02 (data from Reference 13) is shown in Figure IV–1. The chart shows that the National Institutes of Health (NIH) sponsored \$12.0 billion, or 55 percent of the total of federally funded basic research of \$23.4 billion. The National Science Foundation (NSF) and the National Aeronautics and Space Administration (NASA) funding was approximately \$2.8 billion (12 percent) and \$2.6 billion (11 percent), respectively, while the Department of Energy (DOE) sponsored \$2.4 billion, or 10 percent of the total. DoD sponsored approximately \$1.4 billion, or 6 percent, of the total federally funded basic research.

The numbers for FY02 contrast sharply with those in FY79. At that time, DoD sponsored 11 percent of the total federally funded basic research. Thus, over this 23-year period, DoD support of basic research funding managed by federal agencies has decreased by 47 percent, or by almost a factor of two.



**Figure IV–1. Comparison of FY02 and FY79 Basic Research Funding Managed by Federal Agencies**

##### 2. FY03 Appropriations for DoD Science and Technology

The DoD research, development, test, and evaluation (RDT&E) budget appropriation for FY03 is \$57.0 billion. The amount budgeted for 6.1 (basic research) is \$1.417 billion, or 2.49 percent of the RDT&E total.

Figure IV–2 shows the FY03 appropriated funding for science and technology (S&T) by category for each military department, the Defense Advanced Research Projects Agency (DARPA), the Office of the Secretary of Defense (OSD), and other defense agencies.

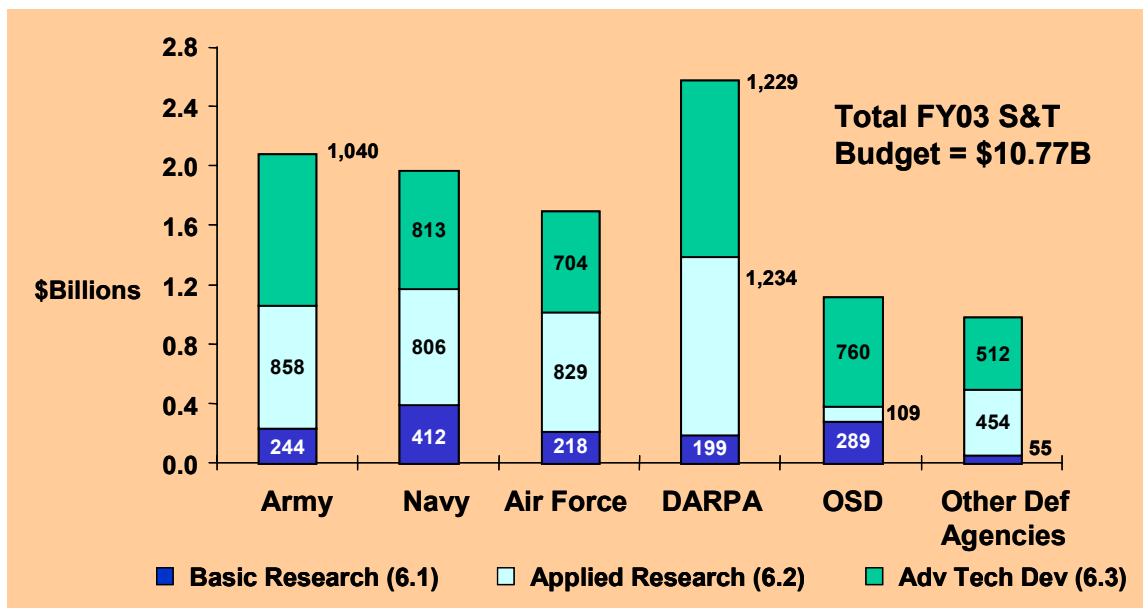


Figure IV–2. FY03 DoD S&T Appropriations Budget

The distribution of basic research funding appropriated in FY03 among the services, DARPA, OSD, and other defense agencies is shown in Figure IV–3. The distribution of FY03 S&T funds among the three S&T funding categories (6.1, 6.2, and 6.3) is shown in Figure IV–4. Eleven percent is invested in basic research, 37 percent in applied research, and 52 percent in advanced technology development.

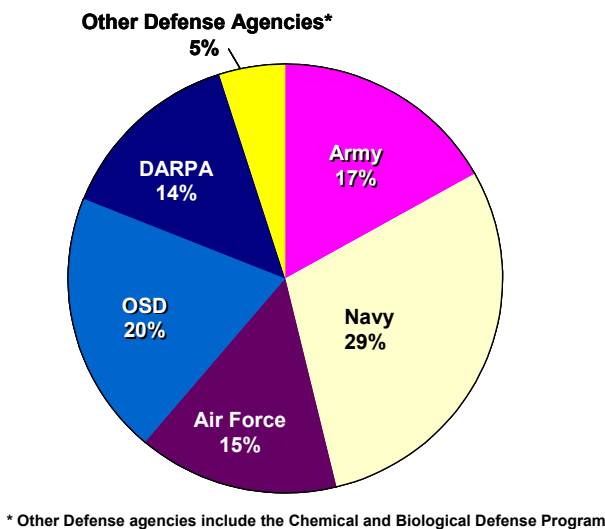


Figure IV–3. Distribution of DoD FY03 Basic Research Program Funding

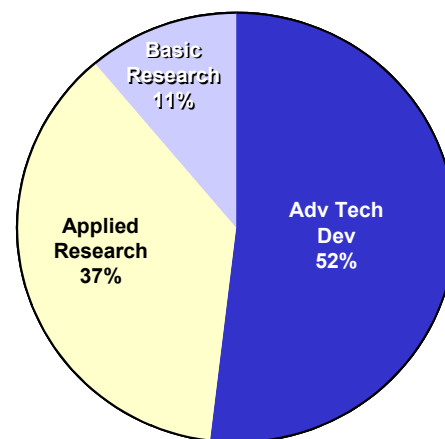
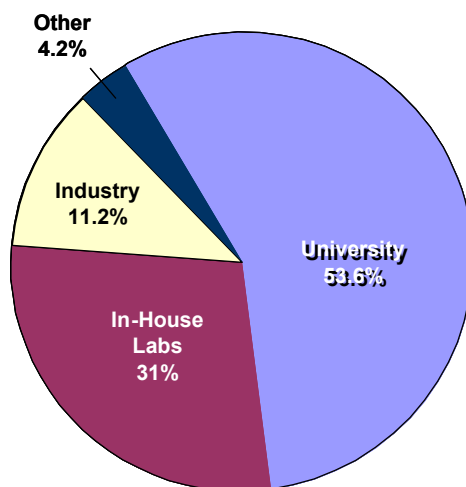


Figure IV–4. Distribution of FY03 S&T Funds Among Basic Research, Applied Research, and Advanced Technology Development

### 3. Funding for Performers of Defense Basic Research

Figure IV–5 compares the FY02 funding levels for the principal performers of DoD basic research: universities (53.6 percent), in-house DoD laboratories (31.0 percent), industry (11.2 percent), and other (4.2 percent). Breakouts for FY03 were not available at the time of publication of this Basic Research Plan. It is expected that the distributions will remain about the same.



Source: National Science Foundation (Reference 14)

**Figure IV–5. Performers of Defense Basic Research in FY03**

### 4. Funding Comparisons by Disciplinary Areas

DoD is a principal supporter of basic research in some key technology areas, as shown in Table IV–1. An analysis of federal funding of basic research to universities indicates that DoD provides the majority of funds for academic research in electrical, mechanical, and astronautical engineering (data from Reference 14, NSF Report). On an overall basis for FY02, DoD provides 31.6 percent of the federal research funding provided to colleges of engineering—a major element of support for the Nation’s engineering programs. Note that the data for FY03 were not available at the time of publication of this BRP. Major changes are not expected.

**Table IV–1. DoD Percentage of Federal Funding to Universities—FY02**

Discipline/ Subdiscipline	DoD Percentage of Federal Funding	
	FY00	FY02
Life Science	2.2	1.6
Psychology	3.0	1.8
Physical Sciences	7.6	9.0
Environmental Sciences	9.7	10.0
Mathematical and Computer Science	13.4	14.4
Mathematics	13.8	—
Computer Science	12.1	—
Other Math and Computer Science	88.5	—
Engineering	31.9	31.6
Aeronautical Engineering	36.7	—
Astronautical Engineering	89.7	—
Chemical Engineering	16.4	—
Civil Engineering	11.1	—
Electrical Engineering	69.0	—
Mechanical Engineering	66.5	—
Material Sciences	32.8	—
Other Engineering	8.6	—
Social Sciences	0.24	0.60
Other Sciences	2.0	2.2
<b>DoD Total to All Agencies</b>	<b>6.3</b>	<b>6.0</b>

Note: The data used in preparing Table IV-1 were taken from Table C-33, Preliminary Federal Obligations for Basic Research, by agency and field of science and engineering, FY02, NSF Publication (Reference 14). Funding data were not provided for the Mathematical and Computer Science subdisciplines or the Engineering subdisciplines for FY02.

## **B. TOTAL FY99–04 FUNDING FOR DEFENSE BASIC RESEARCH**

Funding for all DoD activities is portrayed in the DoD budget by program elements (PEs), which are numbered by five nonzero digits. All R&D PEs have for the first nonzero digit the number “6.” Further, if the PE refers to an R&D activity that is basic research, the second nonzero digit is a “1.” The letter appended to the PE number denotes the service or agency responsible for its execution: “A” for Army, “N” for Navy, “F” for Air Force, “E” for DARPA, “D” for OSD, etc. Table IV–2 presents all PEs in basic research for the years FY99 through FY04.

**Table IV–2. DoD Basic Research Funding by  
Program Element for FY99–04 (\$Millions)**

PE	Title	FY 1999	FY 2000	FY 2001	FY 2002	FY 2003	FY 2004
<b>Services</b>							
<b>Army</b>							
0601101A	In-House Laboratory Independent Research	12.1	13.9	14.4	13.7	20.6	24.1
0601102A	Defense Research Sciences	121.9	123.5	136.9	135.5	140.5	128.8
0601103A	University Research Initiatives						71.6
0601104A	University and Industry Research Centers	42.3	64.9	59.4	71.7	83.3	84.8
0601105A	Force Health Protection						9.8
0601114A	Defense Experimental Program To Stimulate Competitive Research						9.7
0601228A	Historically Black Colleges and Universities/Minority Institutions						14.1
	<b>Total Army</b>	<b>176.3</b>	<b>202.3</b>	<b>210.8</b>	<b>220.9</b>	<b>244.4</b>	<b>342.9</b>
<b>Navy</b>							
0601103N	University Research Initiatives						70.7
0601152N	In-House Laboratory Independent Research	14.6	15.5	16.2	16.1	16.0	17.4
0601153N	Defense Research Sciences	339.4	351.4	378.5	378.7	393.6	368.5
	<b>Total Navy</b>	<b>354.0</b>	<b>366.9</b>	<b>394.7</b>	<b>394.8</b>	<b>412.3</b>	<b>456.6</b>
<b>Air Force</b>							
0601102F	Defense Research Sciences	197.2	208.2	212.2	221.7	217.9	204.8
0601103F	University Research Initiatives						105.2
0601108F	High-Energy Laser Research Initiatives						12.1
	<b>Total Air Force</b>	<b>197.2</b>	<b>208.2</b>	<b>212.2</b>	<b>221.7</b>	<b>217.9</b>	<b>322.1</b>
<b>Total Services</b>		<b>727.5</b>	<b>777.4</b>	<b>817.6</b>	<b>837.5</b>	<b>874.6</b>	<b>1,121.6</b>
<b>Defense Agencies</b>							
<b>Office of Secretary of Defense</b>							
0601101D	In-House Laboratory Independent Research	2.1	2	2	2.1	2.0	
0601103D	University Research Initiatives	220.4	223.4	293	249	234.8	
0601105D	High-Energy Laser Initiatives	0	0	0	11.8	11.7	
0601110D	Gulf War Illness FY99–01 and Force Health Protection FY02–04	22.6	24.6	27.8	36.4	14.8	
0601111D	Government/Industry Cooperative Research	4.2	6.1	6.7	9.2	8.9	
0601114D	Def Exper Prog To Stimulate Competitive Research	0	0	21.8	16.8	16.5	
	<b>Total OSD</b>	<b>249.3</b>	<b>256.1</b>	<b>351.3</b>	<b>325.3</b>	<b>288.7</b>	<b>0</b>
0601101E	DARPA	57.4	63	109	141.9	199.0	151.0
	Defense Research Sciences						
<b>Chemical and Biological Defense Program</b>							
0601384BP	Chemical and Biological Defense	28.8	42.7	39.6	44.8	54.8	35.8
<b>Total Defense Agencies</b>		<b>335.5</b>	<b>361.8</b>	<b>499.9</b>	<b>512.0</b>	<b>542.5</b>	<b>186.8</b>
<b>Total DoD</b>		<b>1,063.00</b>	<b>1,139.20</b>	<b>1,317.50</b>	<b>1,349.5</b>	<b>1,417.1</b>	<b>1,308.4</b>

**Note 1:** Some columns do not add exactly to the totals due to rounding.

**Note 2:** Some program elements may be devolved in FY04, and budget lines will change accordingly.

## **CHAPTER III**

### **DEFENSE BASIC RESEARCH PROGRAM OVERVIEW**

#### **A. CHARACTER AND MANAGEMENT OF PROGRAM**

##### **1. Character of Defense Basic Research**

Basic research is concerned with the discovery and development of fundamental knowledge and understanding, generally without regard to a specific application. Specific applications are generally addressed by applied research, although it is difficult to state hard and fast rules for delineating the boundary between basic research and applied research. Rather, basic research should enable many potential applications and uses. Likewise, *defense* basic research is concerned with the discovery and development of fundamental knowledge and understanding, focusing on future technology applications benefiting *national defense*. Although end uses may differ, the character of *Defense* basic research is mostly indistinguishable from any other research in a similar scientific or engineering area. Where it is distinguishable is more by the *researcher* and his or her motivation than by the *research* as such; that is, the performer should always be aware of opportunities to benefit defense even when his or her research blends into similar research activities supported by other federal research programs. Such blending is in fact highly desirable as it increases the influx of fresh ideas for defense applications.

##### **2. Management of Defense Basic Research**

Defense research is managed mainly by or through the three service research offices—the Army Research Office (ARO), the Office of Naval Research (ONR), and the Air Force Office of Scientific Research (AFOSR)—and the Defense Advanced Research Projects Agency (DARPA). Oversight of the entire Basic Research Program is the responsibility of the Director for Basic Sciences in the Office of the Deputy Under Secretary of Defense for Laboratories and Basic Sciences (DUSD(LABS)), located in the Office of the Director of Defense Research and Engineering (DDR&E).

##### **3. Strategic Research Areas**

Strategic Research Areas (SRAs), described in more detail in Chapter VI, are areas of particular interest and benefit to DoD. SRAs are not projects in themselves; rather, they take advantage of ongoing basic research projects that might be nearing fruition (i.e., application) if combined with other research projects. SRAs identify common objectives that these research projects could pursue simultaneously to increase the opportunities for earlier transitions.

##### **4. International Strategy**

A key element of the Basic Research Plan is increased international awareness and interface. Therefore, it is critical that DoD maintain an expert knowledge of basic research activities and capabilities throughout the world. Intellectual capacity is not unique to the United States. An international element of the DoD Basic Research Plan can help achieve program objectives. The goal is to seek out research in foreign government laboratories and academic institutions where world-class research in the 12 Basic Research Areas and the SRAs are performed. There are

many ways to accomplish this goal, from review of research publications, to attendance at symposia, to joint research projects.

DDR&E supports interaction with all allies on the Multidisciplinary University Research Initiative (MURI) and other research topics. We have begun a dialog with The Technical Cooperation Program (TTCP) member countries to encourage them to fund research in MURI topic areas so that a mutual exchange might occur. Another goal is to establish Master Information Exchange Agreements (MIEAs) with a number of our allies and friendly foreign countries. Under annexes to these arrangements, formal exchanges of research data can occur.

The Engineer and Scientist Exchange Program (ESEP) presents another excellent opportunity for mutual understanding of research capabilities. ESEP participation by DoD personnel and facilities is highly encouraged.

DoD researchers should take maximum advantage of the international field offices operated by Army, Navy, and Air Force. These offices report on international research capabilities and serve as centers of expertise in international science. They also fund programs aimed at bringing DoD and foreign researchers together with discussions aimed at apprising DoD of foreign research advances.

## **B. COMPOSITION OF PROGRAM**

The Basic Research Program supports a wide range of activities spanning many scientific and engineering disciplines to provide a strong technical foundation to meet the diverse needs of the DoD services, agencies, and organizations. The Basic Research Program is primarily composed of two main elements: Defense Research Sciences and University Research Initiatives.

### **1. Defense Research Sciences**

The Defense Research Sciences programs conducted by the Army, Navy, Air Force, DARPA, and the Office of the Secretary of Defense comprise the largest component and the core of the DoD Basic Research Program. In FY03, the Defense Research Sciences programs totaled \$1,163 million (85 percent) of the total basic research funding of \$1,365 million. The Defense Research Sciences programs represent the largest source of DoD funding of university research, with the majority of the research being conducted by single investigators.

The core research disciplines are described in Chapter V, Basic Research Areas. The disciplines are coordinated by tri-service committees, the Scientific Planning Groups (Appendix A), with DARPA participation where appropriate.

### **2. University Research Initiative**

The University Research Initiative (URI) is a collection of specialized research programs performed by academic research institutions. The URI program activities seek to improve the quality of defense research carried out by universities and support the education of engineers and scientists in disciplines critical to national defense needs. The URI program is administered by the DDR&E Office of Basic Sciences and is managed by the ARO, ONR, AFOSR, and DARPA. In FY03, the URI funding level was \$222 million, or 16 percent of the total DoD basic research budget.

A major component of the URI program, the MURI program, supports strong interdisciplinary/multidisciplinary programs that are carried out by multidisciplinary academic teams,

often involving more than one university, working on research projects of strategic interest to DoD. The MURI program is described in detail in Chapter VII. Another important component of URI, the National Defense Science and Engineering Graduate (NDSEG) Fellowship Program, is described below as well as later in Section C of this chapter.

***a. Defense University Research Instrumentation Program***

Research instrumentation is an essential part of the research infrastructure that underpins universities' long-term capabilities to continue to perform cutting-edge defense research. The Defense University Research Instrumentation Program (DURIP) helps to sustain that research infrastructure by supporting university researchers' purchases of major items of equipment costing \$50,000 or more—items that rarely can be acquired within budgeted amounts of single-investigator awards. The DURIP's investment in major instruments complements the investments of military department and defense agency programs in more modest equipment items. In FY03, DURIP provided \$26.9 million for major research equipment purchases in support of DoD's S&T investment of \$1.2 billion in basic, applied, and advanced university research.

***b. National Defense Science and Engineering Graduate Fellowship Program***

The NDSEG Fellowship Program is sponsored by AFOSR, ARO, and ONR. DoD is committed to increasing the number and quality of our nation's scientists and engineers. The actual number of awards varies from year to year, depending upon the available funding. Almost 300 fellowships were awarded in 2001. The NDSEG fellows do not incur any military or other service obligations.

NDSEG fellowships are highly competitive and will be awarded for full-time study and research leading to doctoral degrees in mathematics, physics, biology, ocean, and engineering sciences. Preference will be given to applicants who indicate an intention to pursue a doctoral degree in, or closely related to, one of the following specialties: aeronautical and astronautical engineering; biosciences (excludes toxicology); chemical engineering; civil engineering; chemistry; cognitive, neural, and behavioral sciences; computer science; electrical engineering; geosciences (includes terrain, water, and air); material science and engineering; mathematics; mechanical engineering; naval architecture and ocean engineering; oceanography (includes ocean acoustics); and physics (includes optics).

The NDSEG Fellowship Program is open only to applicants who are citizens or nationals of the United States; persons who hold permanent resident status are not eligible to apply. NDSEG fellowships are intended for students at or near the beginning of their graduate study in science or engineering. Applications are encouraged from women, persons with disabilities, and minorities, including members of ethnic minority groups such as Native American, African American, Hispanic, Native Alaskan (Eskimo and Aleut), or Pacific Islander (Polynesian or Micronesian).

**3. Other Programs**

***a. In-House Laboratory Independent Research***

The In-House Laboratory Independent Research programs allow defense laboratories to conduct quality basic research in the support of laboratory missions and to provide a research environment conducive to the recruitment and retention of outstanding engineers and scientists. Capitalizing on the availability of specialized research facilities and capabilities, the in-house

research program typically involves militarily relevant research that would not or could not be accomplished elsewhere. The in-house program totaled approximately \$42 million in FY03, or about 3 percent of the total basic research funding.

***b. Historically Black Colleges and Universities/Minority Institutions***

The DoD Infrastructure Support Program for Historically Black Colleges and Universities/Minority Institutions (HBCU/MI) program, separately budgeted as part of DoD's applied research (6.2) element, is administered by the Office of Basic Sciences. The HBCU/MI program provided approximately \$14 million in FY03 to fund individual researchers, research consortia, instrumentation purchases, and the creation of science and technology centers at eligible institutions.

The HBCU/MI program provides infrastructure support in fields of science and engineering that are important to national defense. Annual solicitations encourage participation of small minority schools as well as research institutions. Competitively awarded grants provide for research, collaborative research, education assistance, instrumentation, and technical assistance. Minority institutions, as defined by the Department of Education, are eligible to compete in four funding areas:

- *Research awards* contribute to the scientific knowledge base in areas important to DoD. Collaborative research allows university professors and students to work directly with military laboratories or other universities as well as with industry or small business partners.
- *Education grants* strengthen academic programs in science, mathematics, and engineering by providing equipment, scholarships, and work/study opportunities designed to attract students and encourage them to pursue degrees and careers in these areas.
- *Equipment grants* help institutions improve their capacity to perform research of interest to DoD and to train students in scientific disciplines. This program provides for the basic laboratory equipment as well as highly sophisticated research instruments.
- *Technical assistance* grants provide for programs designed to enhance the ability of minority institutions in areas such as proposal writing and administration of grants and contracts.

***c. Government–Industry Cooperative University Research***

The Government–Industry Cooperative University Research (GICUR) program combines industry know-how and funding with DoD interests and funding to support university research projects of mutual interest to industry and government. This program is scheduled to be phased out in FY04. In FY03 this program, administered through DARPA, provided DoD funds of \$3.5 million to support four university-based microelectronics research centers. The research is jointly funded by the U.S. semiconductor industry (50 percent), the semiconductor equipment industry (25 percent), and DoD (25 percent). Thus, the leverage is 3:1 for each dollar from the government.

***d. Defense Experimental Program To Stimulate Competitive Research***

The Experimental Program To Stimulate Competitive Research (EPSCoR) was originated by the National Science Foundation (NSF) in 1979 and continues to provide a sheltered competition for university research grants in states that historically have received the least

federal research funding. The intent for EPSCoR is to assist the state institutions to become more successful at receiving competitively awarded federal research funds by building the state-wide institutional infrastructure. DoD became involved in EPSCoR when Congress directed DoD to conduct a similar program and appropriated funds for that effort in FY91. The program is funded in FY03 at approximately \$9 million. The Defense Experimental Program To Stimulate Competitive Research (DEPSCoR) shares the basic goal of EPSCoR and uses the NSF list of EPSCoR-qualified states and territories as the starting point for determining DEPSCoR eligibility. The NSF EPSCoR states and territories qualified in FY03 are:

Alabama	Kentucky	Nevada	South Dakota
Alaska	Louisiana	New Mexico	U.S. Virgin Islands
Arkansas	Maine	North Dakota	Vermont
Hawaii	Mississippi	Oklahoma	West Virginia
Idaho	Montana	Puerto Rico	Wyoming
Kansas	Nebraska	South Carolina	

Not all EPSCoR states/territories are eligible for the DEPSCoR competition each year. Their eligibility is reassessed each year in accordance with guidance provided within the authorizing language (Public Law 103-337, as amended).

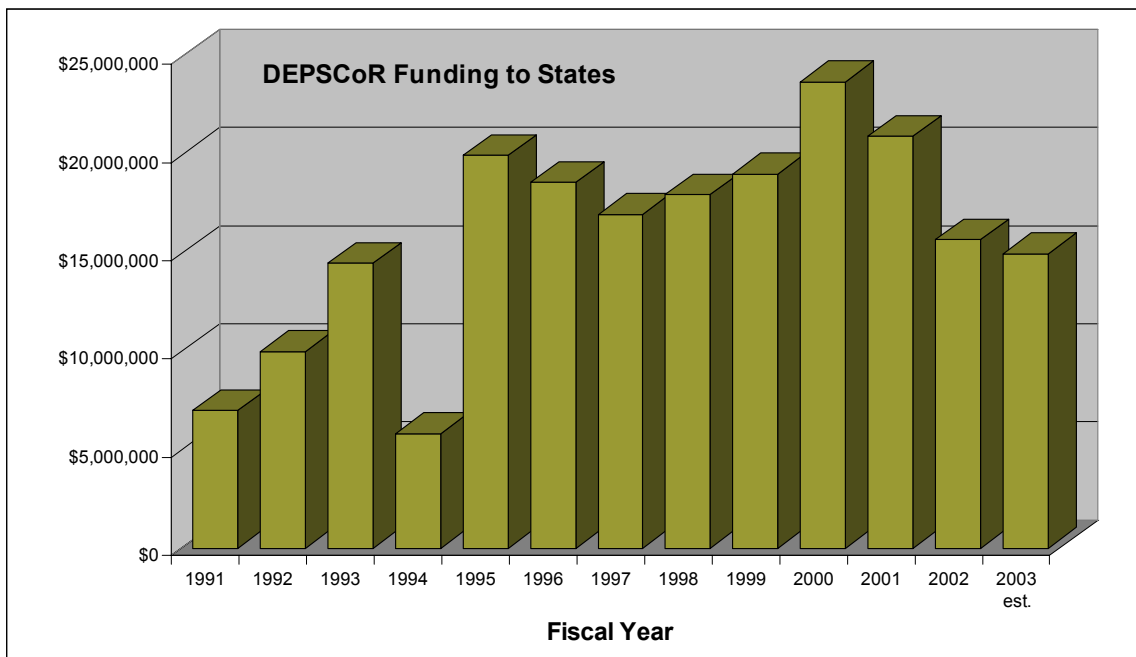
Each EPSCoR state/territory has a committee to coordinate its activities. They are the focal points for solicitation and submission of the state/territorial proposals each year under DEPSCoR. It is the responsibility of these committees to identify and leverage in-state/territory research and development capabilities with federal EPSCoR and EPSCoR-like programs to improve university research capabilities and infrastructure throughout the state/territory with the goal of becoming more successful in full and open federal R&D opportunities.

Active EPSCoR and EPSCoR-like programs are conducted by DoD, DOE, EPA, NASA, NIH, NSF, and USDA. DoD is the third largest funding agency in the federal EPSCoR programs, following NIH and NSF. DoD has awarded more than \$190 million in research grants to EPSCoR states/territories from FY91 through FY02. The annual DEPSCoR awards are presented in Figure III-1.

DoD considers EPSCoR to be a very successful program that brings quality research outcomes to the DoD agencies and services while providing university research investigators with an opportunity to connect with the defense research agenda and managers, thereby enhancing the Nation's research capabilities.

#### ***e. Chemical and Biological Defense Program***

This program element (PE) is the joint-service core research program for chemical and biological (CB) defense (medical and nonmedical). The Basic Research Program aims to improve the operational performance of present and future DoD components by expanding knowledge in relevant fields for CB defense and homeland security. Moreover, basic research supports a joint-force concept of a lethal, integrated, supportable, highly mobile force with enhanced performance by the individual soldier, sailor, airman, or marine. Specifically, the program promotes theoretical and experimental research in the chemical, biological, medical, and related sciences.



**Figure III-1. Annual DEPSCoR Funding to States, FY91-03**

Research efforts are planned to be initiated in CB defense homeland security technologies. This funding supports establishment of a capability for biological terrorism threat assessment research in a Center for Biological Counterterrorism Research. Research areas are determined and prioritized to meet joint-service needs as stated in mission area analyses and joint operations requirements, and to take advantage of scientific opportunities. Basic research is executed by academia, including HBCU/MIs, and government research laboratories. Funds directed to these laboratories and research organizations capitalize on scientific talent, specialized and uniquely engineered facilities, and technological breakthroughs. The work in this program element is consistent with the Joint Service Nuclear, Biological, and Chemical (NBC) Defense Research, Development, and Acquisition (RDA) Plan. Basic research efforts lead to expeditious transition of the resulting knowledge and technology to the applied research (PE 0602384BP) and advanced technology development (PE 0603384BP) activities. This project also includes the conduct of basic research efforts in the areas of real-time sensing and diagnosis and immediate biological countermeasures. The projects in this PE include basic research efforts directed toward providing fundamental knowledge for the solution of military problems.

This project area funds basic research in chemistry, physics, mathematics, life sciences, and fundamental information in support of new and improved detection technologies for biological agents and toxins; new and improved detection technologies for chemical threat agents; advanced concepts in individual and collective protection; new concepts in decontamination; and information on the chemistry and toxicology of threat agents and related compounds.

***Proposed Areas of Focus for FY03***

- *Biological detection*—Continue investigations of novel technologies to rapidly and definitively detect and identify biological warfare (BW) simulants and agents in environmental matrices. Initiate new effort based on a light-scattering approach.

- *Chemical detection*—Continue efforts to detect chemical warfare (CW) agents using solid-state nano-arrays and analysis of degradation products.
- *Protection*—Continue investigations of self-assemblies for protective materials. Initiate effort to investigate agent interactions with microporous surfaces at the molecular level using Magic-Angle Spinning Nuclear Magnetic Resonance (MAS-NMR) spectrometry, X-ray Photoelectron Spectroscopy (XPS), and thermal desorption methods.
- *Decontamination*—Complete investigations of environmentally benign decontamination materials based on peroxycarbonates; transition to the developmental program. Initiate new efforts to develop advanced decontamination materials to allow treatment of sensitive equipment, phase transfer materials, and solution chemistry.
- *Supporting science*—Continue investigations of the behavior of CW agents and simulants under ambient environmental conditions. Make available preliminary volatility and environmental adsorption data to applied research efforts for the Agent Fate program.
- *Information technology*—Continue efforts to directly couple information into warning system by neural coupling.

#### ***Proposed Areas of Focus for FY04***

- *Biological detection*—Continue investigations of novel technologies to rapidly and sensitively detect and identify BW simulants and agents in environmental matrices. Continue biodetection effort based on light scattering approach.
- *Chemical detection*—Continue efforts to detect CW agents using solid-state nano-arrays and analysis of degradation products. Initiate effort to improve data analysis methods. Initiate efforts to assess novel technologies for chemical detection. Continue investigation of novel biological separation methods.
- *Protection*—Continue investigations of self-assemblies for protective materials.
- *Information technology*—Complete effort to directly couple information into warning system by neural coupling.
- *Decontamination*—Continue effort to assess efficacy of novel gas phase decontaminate materials. Initiate new efforts to develop advanced decontamination materials and formulations.
- *Supporting science*—Complete investigations of the behavior of CW agents and simulants under ambient environmental conditions. Make available volatility and environmental adsorption data to applied research efforts for the Agent Fate program.

#### **(1) Homeland Security**

This basic research project emphasizes a better understanding of the threats and risks posed by future bioterrorism activities against the United States. The proliferation of weapons of mass destruction (WMD), to include biological weapons and the scientific expertise necessary to develop biological weapons capability, is one of the greatest threats our nation faces today. Recent terrorism incidents in the United States demand an increased emphasis on research to assess the threat potential of classic, emerging, and genetically engineered biological threats. Funding for this project supports establishing a capability for biological terrorism threat assessment

research in a Center for Biological Counterterrorism Research. Currently there is no single coherent DoD or national scientific program focused on assessing classic and emerging biological threats from a counterterrorism perspective. Risk assessment and threat assessment studies of certain biological agents will require dedicated facilities, equipment, and personnel, and will ultimately entail classified research to prevent disclosure of defensive vulnerabilities. Such a program is not suitable, nor is laboratory capacity available, for placement within existing biodefense programs or facilities.

The proposed area of focus in FY03 will include *microbial threat assessment basic research*, which conducts technology surveys and identifies knowledge gaps with respect to biological threat agents. It will initiate extramural research contract awards for expanded study of basic and molecular biology of threat agents, with emphasis on identification of virulence factors, pathogenic mechanisms, and structural biology.

## **(2) Medical Biological Defense**

This project funds basic research on the development of vaccines and therapeutic drugs to provide effective medical defense against validated biological threat agents, including bacteria, toxins, and viruses. This project also funds basic research employing biotechnology to rapidly identify, diagnose, prevent, and treat disease due to exposure to biological threat agents. Categories for this project include current S&T program areas in medical biological defense (diagnostic technologies, bacterial therapeutics, toxin therapeutics, viral therapeutics, bacterial vaccines, toxin vaccines, viral vaccines) and directed research efforts (anthrax studies and bug-to-drug identification and countermeasures programs).

### ***Proposed Areas of Focus for FY03***

- *Diagnostic technologies*—Conduct basic research on new diagnostic approaches to the early recognition of infection; develop reagents and associated assays to aid in identifying new host and agent-specific biological markers that can be used for early recognition of infection. Continue research to develop, evaluate, and explore new technological approaches for diagnosis of potential BW threat agents and for concentrating and processing clinical samples to support rapid identification and diagnostics.
- *Therapeutics, bacterial*—Correlate metabolic measurements as a rapid and sensitive means to detect antibiotic activity with conventional susceptibility determinations and appropriate animal models of infection. Establish collaborative R&D agreements with pharmaceutical companies to test new and investigational antibiotics. Initiate evaluation of selected therapeutic compounds against *Brucella*.
- *Therapeutics, toxin*—Identify novel human and chimeric monoclonal antibodies by phage display methodology to aid in determining potential as botulinum neurotoxin therapeutics. Perform custom synthesis of lead compounds identified by high-throughput screening assays for botulinum neurotoxin and salmonella enteritidis (SE) toxins. Co-crystallize toxin and lead therapeutics and collect x-ray diffraction datasets. Support development of combinatorial libraries and diversity sets for potential toxin therapeutics.
- *Therapeutics, viral*—Initiate development of intervention strategies for filovirus-induced shock and therapeutic approaches that combine antiviral and antishock drug therapy. Continue research for development of in vitro assays using filovirus polymerase as a potential antiviral drug target.

- *Anthrax studies*—Continue extramural research efforts toward the development and testing of new approaches for the treatment of inhalational anthrax. Focus will continue on two classes of compounds that inhibit the activity of the lethal toxin produced during anthrax infection and on an enzyme target that is critical for the germination and vegetative life cycle of *B. anthracis*.
- *Vaccines, Bacterial*—Develop mutations in various biological agents for in vivo expressed genes to examine the role in virulence. Characterize the mechanism(s) of vaccine resistance in selected strains of various biological agents. Determine mechanisms and correlates of protection with efficacious *B. mallei* vaccines. Evaluate differences in the course of Brucella infection in different mouse strains. Test multiagent vaccine constructs for immunogenicity in animal models.
- *Vaccines, toxin*—Compare the efficacy of constructs with neutralizing epitopes in other domains of botulinum neurotoxin serotypes with the current heavy chain (Hc) subunit toxin vaccine candidates.
- *Vaccines, viral*—Complete investigations of poxvirus immunity to determine the feasibility of replacing Vaccinia Immune Globulin (VIG) with monoclonal antibodies and constructing a new vaccine to replace the *vaccinia* virus vaccine. Investigate the role of cytotoxic T-cells in the Ebola virus-mouse model.

#### **Proposed Areas of Focus for FY04**

- *Diagnostic technologies*—Continue basic research on new diagnostic approaches to the early recognition of infection focusing on technologies compatible with future comprehensive integrated diagnostic systems. Continue to develop reagents and assays for appropriate biological markers for early recognition of infection and identify new host and agent-specific biological markers. Continue research directed toward new technological approaches for diagnosis of biological threat agents and new sample processing technologies.
- *Therapeutics, Bacterial*—Evaluate novel lead antimicrobial compounds in small animal models for anthrax and plague. Initiate in vitro studies on the efficacy of established and investigational antibiotics against *Francisella tularensis* (tularemia).
- *Therapeutics, toxin*—Continue custom synthesis of structural analogs of lead compounds identified by high-throughput screening assays for botulinum and SE toxins. Refine x-ray data for toxin-inhibitor co-crystal structures of most promising botulinum neurotoxin and SE inhibitors. Perform computational chemistry studies to refine lead compound co-crystal structures.
- *Therapeutics, viral*—Continue research for development of intervention strategies for filovirus-induced shock and therapeutic approaches that combine antiviral and anti-shock drug therapy. Complete research for development of in vitro assays using filovirus polymerase as a potential antiviral drug target.
- *Vaccines, bacterial*—Continue studies on the molecular mechanisms of pathogenesis of plague, glanders, and anthrax. Identify additional virulence determinants of Brucella spp. Initiate a study to identify and characterize novel virulence proteins of *F. tularensis*.

- *Vaccines, toxin*—Conduct computational chemistry studies to develop next-generation botulinum neurotoxin and recombinant ricin toxin A-Chain (rRTA) vaccines. Evaluate theoretical feasibility of multivalent vaccines by protein engineering. Evaluate the role of glycosylation or other structural modifications in reducing efficacy of botulinum neurotoxin vaccines.
- *Vaccines, viral*—Complete investigating the role of cytotoxic T-cells in the Ebola virus-mouse model. Initiate research to investigate the role of cytotoxic T-cells in the filovirus model in higher animal species.

### **(3) Medical Chemical Defense**

This project emphasizes understanding of the basic action mechanisms of nerve, blister (vesicating), blood, and respiratory agents. Basic studies are performed to delineate mechanisms and sites of action of identified and emerging chemical threats to generate required information for initial design and synthesis of medical countermeasures. In addition, these studies are further designed to maintain and extend a science base. Categories for this project include science and technology program areas (pretreatments, therapeutics, and diagnostics) and directed research efforts (low-level chemical warfare agent (CWA) exposure and fourth-generation agents).

#### ***Proposed Areas of Focus for FY03***

- *Diagnostics*—Conduct electrophysiological analysis of CWAs in cultured cells. Analyze central nervous system (CNS) and peripheral protein production following soman exposure. Develop new assays for hemodialysis (HD) adducts in plasma and for diagnosing cyanide exposure.
- *Therapeutics*—Incorporate biomarker panels into screening modules. Evaluate combination therapies for neuroprotection efficacy. Evaluate antidotes representing new strategies to improve medical countermeasures.
- *Low-Level Chemical Warfare Agent Exposure*—Continue studies on the neurotoxic effects of low-dose CWA exposure. Continue investigation of alterations in muscle physiology due to repetitive low-dose CWA exposure. Characterize ultrastructural morphology, immunochemistry, and gene expression following low-level chemical exposure. Study the effects of low-level chemical exposure on extracellular neurotransmitter levels. Evaluate organophosphate anhydrolase enzymes for potential use as a biomarker to confirm low-level chemical exposure.
- *Pretreatments*—Target the mechanism of vesicant injury and explore intervention of pro-inflammatory mediators and calcium modulators. Investigate the efficacy of sulfur donors as anticyanide pretreatments. Develop an animal model to test cyanide pretreatment compounds. Express and purify a recombinant human carboxylesterase (CaE) for crystallization. Evaluate the circulatory stability of recombinant bioscavengers.

#### ***Proposed Areas of Focus for FY04***

- *Diagnostics*—Identify molecular intracellular proteomic changes following HD exposure.
- *Therapeutics*—Characterize animal models to test the efficacy of nerve agent bioscavengers. Test a physiologic pharmacokinetic model of CWAs. Determine the

effects of HD on cell structure using multiphoton laser scanning microscopy. Analyze in vitro effects of HD on cellular energy metabolism. Study in vitro biochemical changes induced by HD. Investigate the enzymatic target of HD. Evaluate drug treatment strategies and combinations of therapies for nerve agent-induced seizures.

- *Low-Level Chemical Warfare Agent Exposure*—Identify biomarker(s) to confirm low-level chemical exposure and develop a behavior assessment model. Identify potential medical countermeasures for low-level chemical exposure.
- *Pretreatments*—Continue pretreatment intervention studies of vectors to deliver bio-scavenger genes. Identify the mechanism of action of vesicant pretreatment compounds. Evaluate cyanide toxicity using an inhalation model. Determine the x-ray crystallographic structure of catalytic scavengers. Investigate the efficacy of sulfur donors and methemoglobin formers as cyanide pretreatments.

#### ***f. High-Energy Laser Program***

The High-Energy Laser (HEL) program, funded at \$12 million in FY03, provides basic research aimed at developing fundamental scientific knowledge to support future DoD HEL systems. HEL weapon systems have many potential advantages, including speed-of-light time to target; high-precision, nearly unlimited magazine depth; low cost per kill; and reduced logistics requirements because of no need for stocks of munitions or warheads. As a result, HELs have the potential to perform a wide variety of military missions, including some that are impossible, or nearly so, for conventional weapons. These include interception of ballistic missiles in boost phase; defeat of high-speed, maneuvering antiship and antiaircraft missiles; and the ultra-precision negation of targets in urban environments with no collateral damage. Research conducted under this program develops the technology necessary to enable these and other HEL missions.

The HEL program is part of an overall DoD initiative in HEL science and technology being conducted by the HEL Joint Technology Office (JTO), located in Albuquerque, New Mexico. The goals of the HEL JTO-funded research are to provide the technology to make HEL systems more effective and also to make them lighter, smaller, cheaper, and more easily supportable on the battlefield. In general, efforts funded under this program element are chosen for their potential to have major impact on multiple HEL systems and on multiple service missions. As a result of this focus and of close coordination with the military departments and defense agencies, this program complements other DoD HEL programs that are directed at more specific service and agency needs.

A broad range of technology is addressed in key areas such as chemical lasers, solid-state lasers, beam control, optics, propagation, and free-electron lasers. Research is conducted principally by universities, but also by government laboratories and industry. The program funds theoretical, computational, and experimental investigations. In many cases, these three types of investigations are combined under a single effort, thereby creating synergistic effects between various scientific approaches, which greatly enhance the potential for making important breakthroughs in HEL-related technologies.

To stimulate creative basic research, the HEL JTO—in collaboration with the DUSD(S&T) Basic Research Directorate, the service research offices (ARO, ONR, and AFOSR), and DARPA—developed the High Energy Laser Multidisciplinary Research Initiative (MRI). The HEL MRI was modeled after the MURI program, which is discussed in detail in

Chapter VII. In both cases, research is to be led by university teams. The HEL MRI differs from the MURI in that the topic areas are specific to HEL technology and, to foster technology transfer, the university lead is able to provide some funding to collaborators in industry or Federally Funded Research and Development Centers (FFRDCs).

Research topics for the HEL MRI were developed by ARO, ONR, AFOSR, and DARPA. After discussions among the topic developers, the JTO, and the DUSD(S&T) Basic Research Directorate, the JTO selected six topic areas, involving thrusts from the service research offices and DARPA, for inclusion in the first HEL MRI call for proposals. The six topics and their associated offices are shown in Table III–1.

**Table III–1. MRI Topics**

Topic Number and Title	Lead Office
1. High-Average-Power, Diode-Pumped Solid-State Lasers	DARPA/ARO
2. Affordable High-Energy Laser Systems	AFOSR
3. Atmospheric Propagation and Compensation of High-Energy Lasers	AFOSR
4. High-Power, Lightweight Optics	AFOSR
5. High-Energy Closed-Cycle Chemical Lasers	AFOSR
6. High-Average-Power, Ultra-Short-Pulse, Free-Electron Lasers	ONR

The Broad Agency Announcement (BAA) for the HEL MRI was issued in June 2001. Over 50 letters of intent were received across the six topics; evaluations were conducted and awards were subsequently announced. The formal kickoff meeting was held in September 2002.

The six topic areas shown in Table III–1 overlap the technology thrust areas in the overall prioritized investment strategy of the HEL JTO extremely well. The topics and institutions for the MRI are listed in Table III–2.

**Table III–2. FY02 MRI Selections**

Topic	Institution
Power Scaling with High Spectral and Spatial Coherence	Stanford University
High-Energy Laser Multidisciplinary Research	University of Arizona, MIT
Advanced High-Energy Closed Cycle Iodine Chemical Lasers	University of Denver
Multidisciplinary Research for High-Energy Closed-Cycle Chemical Lasers	University of Illinois
Atmospheric Propagation of High-Energy Lasers: Modeling, Simulation, and Tracking	UCLA
Fabrication, Testing, Coating, and Alignment of Fast Segmental Optics	University of Arizona University of Minnesota
High-Average-Power, Ultra-Short-Pulse, Free-Electron Laser	University of Maryland
Research in Support of High-Average-Power, Free-Electron Laser	Stanford University

The MRI program is for three calendar years followed by an option for two additional years. It is important to note that, assuming good technical progress, these proposals represent a minimum of a 3-year commitment by the HEL JTO. Each program will be reviewed annually. DoD intends to translate the knowledge developed under this program into proof-of-concept

solutions to broadly defined HEL-related military applications as part of further laboratory experiments and field testing.

***g. Force Health Protection***

The DoD Force Health Protection Research Program (FHPRP) builds on findings and successes from a decade of research on Gulf War illnesses to protect the health of those in future military deployments. Results from ongoing research on Gulf War illnesses continue to be transitioned to appropriate branches within DoD, to the Department of Veterans Affairs, and to the Department of Health and Human Services.

The objectives of the FHPRP are to support force health protection concepts to maintain a fit and ready force, to prevent casualties, to provide warfighters with a greater assurance of protection against materiel and operational hazards in future deployments, to improve methods of diagnosing and treating undiagnosed illnesses in veterans, and to coordinate unique DoD research programs in stress-induced dysfunction, toxicology, and epidemiology with research efforts by other federal departments.

The FHPRP has been managed largely through competitive solicitations, with the majority of funded projects going to extramural academic institutions. All research receives scientific peer review independent of DoD. This includes peer review of the projects before award and site reviews of continuing program projects.

The largest intramural effort is support to the DoD Center for Deployment Health. This center manages the 22-year Millennium Cohort Study and coordinates research to develop the Recruit Assessment Program, among other longitudinal epidemiological investigations into improved health monitoring strategies for DoD. The largest extramural grants to date include competitive peer-reviewed grants to Georgetown University; VA Medical Center, San Francisco; and University of Texas, Southwestern Medical Center.

Significant accomplishments include development and establishment of the DoD Birth Defects Registry for early identification of associations with occupational and deployment exposures; development of a diagnostic skin test for Leishmania infection; development and validation of a standardized neuropsychological screening tool that is proving useful for baselining and followup of deployed troops' mental functioning; development of an initial baseline health information and risk factor tool; and improved understanding of risks and safety of pyridostigmine bromide, DEET (N,N-diethyl-meta-toluamide), permethrin, and other chemicals in combination and with operational stressors.

One particularly significant finding is that multiple studies indicate no single factor or unique disease in undiagnosed Gulf War illnesses; however, self-reported symptoms are more prevalent in veterans who deployed to the Persian Gulf. In the first decade after the Gulf War, the main difference in overall health and mortality of Gulf War veterans remains a higher incidence as a result of vehicular accidents; this is being investigated but is currently unexplained.

For the FY02 program, a new solicitation was issued on risk communication. For FY03, the program will continue to support research in the areas of risk communication, neurobiology of stress and immune function, deployment toxicology methods, force health protection epidemiology, health behaviors intervention (including weight management), and deployment health assessment. Beginning in FY04, the FHPRP will become part of the core Army biomedical program, managed by the U.S. Army Medical Research and Materiel Command and remaining within the DoD basic research portfolio.

Funding for this program in FY02 was \$36 million, including congressional add-ons. For FY03 and beyond, projected funding is projected to be \$10 million per year.

### **C. SCIENCE EDUCATION AND INFRASTRUCTURE SUPPORT**

The DoD Basic Research Program also provides education and infrastructure support for the education and training of future talented scientists and engineers and for the improvement of research equipment and instrumentation. Students and modern equipment and facilities are essential ingredients for scientific research.

The Basic Research Program provides for the education and involvement of undergraduate, graduate, and post-doctoral students and young investigators through a variety of policies and programs designed to create a new generation of scientists and engineers who will perform research of importance to DoD and the country in the future. Many individual research grants to universities, as well as multidisciplinary university research grants (such as the MURIs), often include financial support for undergraduate students, graduate students, and post-doctorates in addition to research support for university faculty. Education and training fellowships are provided to outstanding individual scientists and engineering undergraduate and graduate students as part of the URI program element.

DoD also sponsors the NDSEG Fellowship Program. This program provides fellowships to substantial numbers of graduate students majoring in science and engineering areas of interest to DoD.

DoD is collaborating with the NSF on its Research Experiences for Undergraduates Site Program, which funds sites to provide research experiences for undergraduates who may not otherwise have access to research opportunities. DoD has also started a partnership with the Semiconductor Research Corporation Education Alliance to create an industry-matched undergraduate research program in disciplines of interest to the semiconductor and other high-tech industries. Both programs will begin in FY03.

### **D. TRANSITIONS FROM BASIC RESEARCH TO APPLICATIONS**

To be successful, DoD basic research results must eventually lead to providing technologically superior weapon systems and products at a more affordable cost. Basic research must transition to industry and defense laboratories to enable development and engineering programs that result in rational, beneficial, cost-effective, and timely weapon systems.

As highlighted in [Chapter I, Section F](#), the ultimate payoff of basic research is in moving leading-edge technologies into the field. DoD has an excellent record of transitioning technology; however, increased emphasis should be placed on shortening the time for insertion into fielded systems. Insertion will require planning for earlier transitioning of mature research projects. Planning for earlier transitioning is one of the principal objectives of the MURI research grants to universities, the SRA teaming of the Office of Research (ARO, ONR and AFOSR) managers in selected strategic research areas, and the GICUR research requiring university–industry connections.

As part of the basic research review process, for example, AFOSR has documented the transition of basic research outcomes to industry, defense laboratories, and other DoD/governmental organizations. Of the 497 documented transitions for FY00, there were 263 from universities, 196 from the Air Force Research Laboratory, and 38 from industries supported by

AFOSR 6.1 funds. Of the 497 transitions, 299 were to industry, 119 were to DoD or other governmental agencies, and 79 were to Air Force laboratories.

The success stories identified throughout [Chapter VIII](#) are excellent examples of basic research that has transitioned to more advanced research stages or has resulted in new technologies already being utilized in many of today's weapon systems as well as in many nondefense applications.

## **CHAPTER II**

### **THE PLANNING PROCESS**

As discussed in Chapter I, the basic research planning process is an integral part of the DoD science and technology (S&T) planning process. The Office of Basic Sciences in OSD and the individual Service Basic Research Offices have the responsibility to jointly develop the DoD Basic Research Plan (BRP).

The biennial basic research cycle begins with project-level reviews at the individual research agencies (AFOSR, ARO, ONR, DARPA, and the Missile Defense Agency (MDA)). These sessions are followed by a program-level review, called the Defense Basic Research Review, by a panel of non-DoD experts. Budget projections for the next year are prepared and submitted as part of this process. The BRP is based in part on the results of the Defense Basic Research Review.

#### **A.     ROLE OF SERVICES AND AGENCIES IN BASIC RESEARCH PROGRAM**

The DoD services and agencies develop their own specific basic research plans and goals. As many of their technology goals overlap, plans for basic research are coordinated through the Basic Sciences Office as part of the Defense S&T Reliance Process. The majority of the scientific work constituting the DoD Basic Research Program involves 12 technical disciplines, which are coordinated by Scientific Planning Groups (SPGs) consisting of disciplinary program managers from each of the services. The SPGs and the Strategic Research Area (SRA) Coordinating Committees provide coordinated tri-service oversight for research in their respective areas. The SPGs concentrate on their specific disciplinary areas, whereas the SRA coordinating committees concentrate on interdisciplinary approaches in their focus areas.

Each service and agency is responsible for developing, reviewing, and assessing its individual research plans, which are coordinated by the SPGs. As part of the Defense Basic Research Review process, the Office of Basic Sciences reviews and assesses the quality, technical content, relevance, and focus of the overall service and DoD-wide programs.

#### **B.     BASIC RESEARCH AND THE RELIANCE PROCESS**

The DoD Basic Research Program is executed within the framework of the DoD S&T Reliance process and is overseen by the Office of Basic Sciences. The biennial Defense Basic Research Review process is used to monitor the quality, coordination, DoD relevance, and realistic funding of the research projects. The Director of Basic Sciences chairs the Defense Basic Research Advisory Group (DBRAG), which provides oversight of the Basic Research Program. The Defense Basic Research Review Panel consists of technical experts from academia, industry, and not-for-profit research organizations.

The DBRAG is chaired by the Director of the Office of Basic Sciences, and includes the Directors of the Army, Navy, and Air Force basic research organizations as well as a basic research representative from DARPA. The DBRAG meets on a regular basis to share information and coordinate among the participants.

The role of these and other groups in evaluating the Basic Research Program as a whole is discussed in Section D of this chapter.

### **C. A FLEXIBLE AND BALANCED INVESTMENT PORTFOLIO**

The military services and defense agencies coordinate their individual research investment plans through the Defense S&T Reliance process as described in the previous section. The Defense S&T Reliance process establishes and implements joint planning, joint research partnerships, or lead-service assignments among the military services for the technical disciplines of the BRP. Each research area is examined closely by its participants to establish areas of common interest and to provide opportunities for cooperative leverage. Such joint planning and coordination of programs provides a broader research effort and more efficient support of a more balanced investment portfolio than could be provided by a single-service effort. For example:

- The Army emphasizes information technologies (mathematics, computer sciences, electronics) for digitizing the battlefield, materials science for armor and soldier protection, optical sciences for target recognition, chemistry and biological sciences for chemical and biological agent defense, and geosciences for terrain-related knowledge relevant to battlefield mobility prediction.
- The Navy has a full-spectrum program that places special emphasis on a wide range of ocean science activities, including predicting weather and currents, mapping the ocean floor, using acoustics to detect objects in the ocean, and conducting biotechnological research such as understanding and mimicking communications between mammals.
- Air Force expertise is concentrated in the aerospace sciences, materials, physics, electronics, chemistry, life sciences, and mathematics. Applications include air vehicles, space systems, and command, control, communications, computers, and intelligence (C<sup>4</sup>I).

Besides directly supporting their military departments, DoD laboratories serve as agents for DARPA, MDA, and other defense agencies. These programs interact and are coordinated by the SPGs, discipline by discipline, and through the OSD-sponsored multidisciplinary programs. The OSD Basic Sciences Office, working with the DBRAG, exercises oversight over the research program as a whole.

Even though DoD provides only about 6 percent of all federal basic research funding ([Chapter IV, Figure IV-1](#)), DoD is a significant source of federal funding of university research in several disciplines. DoD is a major funding source in electrical and mechanical engineering (providing 69 percent and 66.5 percent, respectively, of the R&D support in this area), computer sciences (12.1 percent), and mathematics (13.8 percent) (details in [Chapter IV, Table IV-1](#)). DoD is a major source of funding in materials, optics, and oceanography. In some specific areas, DoD is the only source of basic research funding (e.g., in the support of vacuum electronics needed for radiation-hardened electronics used in radar and space systems).

## **D. QUALITY AND RELEVANCE OF BASIC RESEARCH PROGRAM**

### **1. Scientific Planning Groups**

The primary responsibility for ensuring the quality and relevance of the basic research in the basic research areas rests with the Scientific Planning Groups. A list of the current SPGs and their members is provided in [Appendix A](#). The SPGs meet regularly to coordinate related activities in their disciplinary areas. The coordination of the DoD Basic Research Program is successful because of the quality of the SPG leadership.

### **2. Strategic Research Area Coordinating Groups**

The primary responsibility for ensuring that the Strategic Research Areas are coordinated and are emphasized by the services and DARPA rests with the SRA Coordinating Groups. As is the case for the SPGs, the SRA Coordinating Groups involve all three services and DARPA and meet regularly to coordinate the activities in their specific strategic areas. The SRA Coordinating Group membership is included in [Appendix A](#).

### **3. Defense Basic Research Advisory Group**

The Defense Basic Research Advisory Group coordinates at the next higher level among the service and DARPA basic research offices. The DBRAG serves as the primary organization to establish a coordinated research program that supports the DoD mission. The committee also assists in the clarification of issues and policy. The DBRAG supports the overall preparation of the BRP submitted to the Deputy Under Secretary of Defense for Laboratories and Basic Sciences (DUSD(LABS)). The DBRAG membership is included in [Appendix A](#).

### **4. Defense Basic Research Review Panel**

The Defense Basic Research Review Panel, consisting of technical experts from academia, industry, and not-for-profit organizations, evaluates the DoD basic research programs for vision, technical content, depth, relevance, and quality. The results of the reviews are provided to the DBRAG. The Defense Basic Research Review Panel membership is included in [Appendix A](#).

### **5. Non-DoD Government Scientific Planning Group Review Panel**

For the basic research review conducted in June 2002, a review panel composed of members from other federal research agencies was assembled to review the specific SPG areas. A list of the non-DoD government SPG Review Panel members is included in [Appendix A](#). This panel provided an evaluation from the perspective of the basic research being conducted by their organizations. This provided a heading check to ensure that the DoD research funds were being invested wisely and did not significantly duplicate or overlap other agency programs.

### **6. Deputy Under Secretary of Defense for Laboratories and Basic Sciences**

The Office of the Deputy Under Secretary of Defense for Laboratories and Basic Sciences uses the basic research review process to ensure the quality and relevance of the research conducted by the DoD components, and to keep the focus on the DoD mission. The Director for Basic Sciences exercises oversight over the entire DoD Basic Research Program and reports to the DUSD(LABS), who provides feedback and guidance to the Director for Basic Sciences in the context of the larger S&T program and other DoD strategic interests.

## APPENDIX C: GLOSSARY OF ABBREVIATIONS AND ACRONYMS

ABL	airborne laser	CW	chemical warfare
AFOSR	Air Force Office of Scientific Research	CWA	chemical warfare agent
AGAS	Affordable Guided Airdrop System	DAR	differential absorption radar
ARI	Army Research Institute	DARPA	Defense Advanced Research Projects Agency
ARL	Army Research Laboratory	DBRAG	Defense Basic Research Advisory Group
ARO	Army Research Office	DDR&E	Director of Defense Research & Engineering
ARPANet	Advanced Research Projects Agency Network (precursor to the World Wide Web)	DDS	direct digital synthesis
ASBREM	Armed Services Biomedical Research Evaluation and Management Committee	DEPSCoR	Defense Experimental Program to Simulate Competitive Research
ASDS	Advanced Seal Delivery System	DNA	deoxyribonucleic acid
ATD	Advanced Technology Demonstration	DoD	Department of Defense
AWACS	Airborne Warning and Control System	DOE	Department of Energy
		DTAP	Defense Technology Area Plan
		DURIP	Defense University Research Instrumentation Program
BAA	Broad Agency Announcement	DUSD(LABS)	Deputy Under Secretary of Defense for Laboratories and Basic Sciences
BACIMO	Battlespace Atmospheric and Cloud Impacts on Military Operations	DUSD(S&T)	Deputy Under Secretary of Defense for Science and Technology
BioMEMS	bio-microelectromechanical systems	EFP	explosively formed penetrator
bR	bacteriorhodopsin	EM	electromagnetic
BRP	Basic Research Plan	EPA	Environmental Protection Agency
BW	biological warfare	EPSCoR	Experimental Program to Stimulate Competitive Research
C <sup>3</sup> I	command, control, communications, and intelligence	ESEP	Engineer and Scientist Exchange Program
C <sup>4</sup> I	command, control, computers, communications, and intelligence	FEM	finite element method
C <sup>4</sup> ISR	command, control, communications, computers, intelligence, surveillance, and reconnaissance	FET	field-effect transistor
		FHPRP	Force Health Protection Research Program
CaE	carboxylesterase	FLIR	forward-looking infrared
CARP	Computed Aerial Release Point	GEAE	General Electric Aircraft Engines
CAV	composite armored vehicle	GICUR	Government–Industry Cooperative University Research
CB	chemical and biological	GPS	Global Positioning System
CBDC	Chemical and Biological Defense Command	HBCU/MI	Historically Black Colleges & Universities/Minority Institutions
CBRNE	chemical, biological, radiological, nuclear, and explosive	Hc	heavy chain
CBW	chemical and biological warfare	HCF	High-Cycle Fatigue (Initiative)
CCD	charge-coupled device	HD	hemodialysis
CCMC	Community Coordinated Modeling Center	HEL	high-energy laser
CDS	Container Delivery System	HEMT	High-Electron-Mobility Transistor
CME	coronal mass ejection	HSI	human–system interface
CNS	central nervous system	IMETS	Integrated Meteorological System
COC	combat operations center	IR	infrared
CTIS	Combat Terrain Information System		

JTO	Joint Technology Office	PD	probability of detection
JWCO	Joint Warfighting Capability Objective	PE	program element
JWSTP	Joint Warfighting Science and Technology Plan	PFA	probability of false alarm
		PGM	precision-guided munition
		QDR	Quadrennial Defense Review
LED	light-emitting diode	R&D	research and development
LIDAR	light detection and ranging	RDA	research, development, and acquisition
LES	large-eddy simulation	RDM	recognitional decisionmaking
MANTECH	Manufacturing Technology	RDT&E	research, development, test, and evaluation
MAS–NMR	Magic-Angle Spinning Nuclear Magnetic Resonance	RF	radio frequency
MDA	Missile Defense Agency	RNP	reactive nanoparticle
MEMS	microelectromechanical systems	RPC	Rapid Prototyping Center
MIEA	Master Information Exchange Agreements	RPM	recognition-primed model
MMW	millimeter wave	rRTA	recombinant ricin toxin A-chain
MOUT	Military Operations on Urbanized Terrain	S&T	science and technology
MRI	Multidisciplinary Research Institute; magnetic resonance imaging	SBIR	Small Business Innovative Research
MRUVV	Mission-Reconfigurable Unmanned Underwater Vehicle	SBIRS	Space-Based Infrared System
MURI	Multidisciplinary University Research Initiative	SCWO	supercritical water oxidation
		SE	salmonella enteritidis
		SETAC	Shipboard Electronics Thermoacoustic Cooler
NABL	nocturnal atmospheric boundary layer	SIE	singular integral equation
NASA	National Aeronautics and Space Administration	SMEI	Solar Mass Ejection Imager
NAWC	Naval Air Warfare Center	SPG	Scientific Planning Group
NBC	nuclear, biological, and chemical	SRA	Strategic Research Area
NDSEG	National Defense Science and Engineering Graduate	STE	simulated task environment
Ni <sub>2</sub> MnGa	nickel magnesium gallide	STRATCOM	U.S. Strategic Command
NIH	National Institutes of Health	T <sub>c</sub>	critical temperature
NMR	nuclear magnetic resonance	TE	thermoelectric
NOAA	National Oceanic and Atmospheric Administration	TKML	Tacit Knowledge for Military Leadership
NRO	Naval Reconnaissance Office	TTCP	The Technical Cooperation Program
NSF	National Science Foundation	UAV	unmanned aerial vehicle
NSWC	Naval Surface Warfare Center	UNOLS	University National Oceanographic Laboratory System
NSWP	National Space Weather Program	URI	University Research Initiative
		USARIEM	U.S. Army Research Institute of Environmental Medicine
ODUSD(S&T)	Office of the Deputy Undersecretary of Defense for Science and Technology	USDA	United States Department of Agriculture
ONR	Office of Naval Research	USD(AT&L)	Under Secretary of Defense for Acquisition, Technology, and Logistics
OSD	Office of the Secretary of Defense	UV	ultraviolet
OUSD(LABS)	Office of the Secretary of Defense for Laboratories and Basic Sciences	VIG	Vaccinia Immune Globulin
OXR	Offices of Research (collectively the ARO, ONR, and AFOSR)	WMD	weapons of mass destruction
PAD	Precision Air Delivery (program)	XPS	X-ray Photoelectron Spectroscopy
PbMgNBO <sub>3</sub>	lead magnesium nitroboric oxide		